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Effects of The Transportation and Climate Initiative on the Maine Economy: An Analysis of Cap-And-Invest and Its Heterogeneous Impacts on Rural and Urban Households

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EFFECTS OF THE TRANSPORTATION AND CLIMATE INITIATIVE ON THE MAINE ECONOMY: AN ANALYSIS OF CAP-AND-INVEST AND ITS HETEROGENEOUS IMPACTS ON RURAL AND URBAN HOUSEHOLDS

by

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ABSTRACT

In December 2020, a memorandum of understanding (MOU) was released by the Transportation and Climate Initiative Program (TCI-P), a collaboration of 13 jurisdictions in the New England and Mid-Atlantic regions of the United States. Modeled on the Regional Greenhouse Gas Initiative (RGGI), the TCI-P follows a cap-and-invest framework to reduce emissions from the transportation sector by 26% from 2022 to 2032. Since the TCI-P is expected to raise the price of gasoline by 5¢ to 9¢ per gallon, there has been concern that some populations may be disproportionately affected. The present research studies the potential heterogeneous impacts of the TCI-P on rural and urban populations within the state of Maine. The author hypothesizes that rural Mainers will be more sensitive (i.e., elastic) to changes in the price of gasoline, and that ultimately they will bear a disproportionate burden from the TCI-P.

Research methods rely on a short-run household price elasticity of demand estimate from Spiller, Stephens, and Chen (2017), which is adapted to reflect the demographic characteristics of rural and urban households in Maine. Elasticities are weighted according to their relative importance. Reductions in households' transportation emissions are calculated for each population, along with the economic loss and burden, to reveal the expected heterogeneous impacts of the TCI-P in Maine. Results find a short-run, weighted elasticity for rural households of -0.97. The adapted elasticity for urban households is found to be -0.75, for a Maine average of -0.87. Given price increases of 5¢ or 9¢, rural households are shown to face relatively small but disproportionate economic losses and burdens as compared to urban households. The burden on rural households is

estimated to range from $52 to $92 per year, while the burden on urban households is estimated to range from $51 to $91 per year. These values represent between 2% and 4% of fuel expenditures for the average Maine household. The economic burden of a 9¢ increase in the price of gasoline amounts to approximately 2% of the variable costs of driving a used vehicle and just 1% of the total driving costs of a used vehicle. The median household income in rural and urban Maine is $53,701 and $60,571, respectively.

The author concludes with a series of investment portfolios and messaging and communication strategies that have the potential to increase public support for the TCI-P. This research provides key insights into potential heterogeneous impacts on Maine households while contributing to the public discourse on an important topic in climate policy.

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TABLE OF CONTENTS

FIGURES LIST

TABLES LIST

CHAPTER I

INTRODUCTION

As the United States continues to face the effects of a changing climate, the responsibility to minimize greenhouse gas (GHG) emissions is clear. A few years ago, I warned that climate change would bring an increased prevalence of ticks, damage to transportation infrastructure from flooding, and unstable weather conditions for agriculture (Somes 2018). A recent report from the Scientific and Technical Subcommittee echoed these concerns, adding sea level rise, ocean acidification, and warming of coastal waters as other notable effects of climate change in Maine (Arnold et al. 2020). These are not threats to be confronted in the distant future. The effects of climate change have already begun, and the longer we wait to address them, the more severe they will become.

The U.S. is the second largest emitter of CO_2 in the world today (Fleming 2020), and after the U.S. pulled out of the Paris Climate Accord in November of 2020 (Hersher 2019), the task of mitigating GHG emissions largely fell to state and local governments, private companies, and individuals. Approximately two dozen states, accounting for 40% of U.S. emissions, already have policies in place to meet commitments made at the Paris Accord (Cooper 2018), which welcomes all non-Party stakeholders to participate in climate change mitigation efforts. This includes financial institutions, civil society groups, cities, provinces, or states (United Nations 2019). Fortunately, the U.S. rejoined the Paris Accord after President Joseph R. Biden's administration took office in January

2021 (Rott 2021). Despite its commitments, the United States and other top polluting nations are falling woefully short of goals to keep temperatures below 1.5° Celsius or 2° Celsius above preindustrial levels, which were established by the Accord in 2015 (Olhoff et al. 2017; Gold, Bender, and Landers 2021). Thus, it is imperative that states such as Maine take immediate action to curb GHGs.

With the support of the Maine state legislature, Governor Janet Mills assembled the Maine Climate Council (MCC) in 2019.[1] The MCC is comprised of a group of political and industry representatives and climate change experts tasked with coming up with strategies to cut emissions 45% by 2030 and 80% by 2050 (MCC n.d.). The MCC is supported by the Scientific and Technical Subcommittee and working groups that focus on specific aspects of emissions mitigation, adaptation, and resilience. These include the Natural and Working Lands Working Group; the Coastal and Marine Working Group; the Buildings, Infrastructure and Housing Working Group; the Community Resilience Planning, Public Health, and Emergency Management Working Group; the Energy Working Group; and the Transportation Working Group (MCC n.d.). Arguably the most important among them is the Transportation Working Group (TWG), since the transportation sector accounts for 54% of Maine's GHG emissions (Maine Department of Environmental Protection [MeDEP] 2020). Future emissions reductions in Maine must rely on the mitigation of this outsized emissions source (Taylor and Cushman 2020; MeDEP 2020).

Included in the TWG's report to the MCC was a list of recommendations to expand the electric vehicle fleet, lower the carbon intensity of internal combustion

[1] An Act to Promote Clean Energy Jobs and to Establish the Maine Climate Council, 38 M.R.S.A. §577-A (2019).

engines, and reduce vehicle miles traveled (VMT). Importantly, the report also listed the Transportation and Climate Initiative Program (TCI-P) as a specific action the state could take to further reduce emissions, although the TWG's support for the initiative was not universal (Taylor and Cushman 2020, 5-47). Established in 2010, the TCI-P is a regional cap-and-invest program originally comprised of 12 northeast and mid-Atlantic states plus the District of Columbia (LeBlanc 2020). The TCI-P follows a similar emission reduction strategy as the Regional Greenhouse Gas Initiative (RGGI), of which Maine is a member ("The Regional Greenhouse Gas Initiative" 2020). The TCI-P is explained in greater detail below. In 2019, the Georgetown Climate Center (GCC) reported that the TCI-P could result in 20-25% fewer emissions across participating jurisdictions by the year 2032 (GCC 2019). More recent estimates show the TCI-P will result in a 26% decline in transportation emissions and up to $2 billion in annual revenues if all 13 jurisdictions participate (GCC 2020b). However, the Mills administration has stated publicly that Maine will not be joining the TCI-P at this time, citing concerns over changes in the price of gasoline disproportionately affecting rural Mainers (LeBlanc 2020). Future decisions regarding TCI-P membership will likely depend on whether these perceptions change.

It is therefore important that the potential effects of the TCI-P are properly understood. State government should be reasonably confident the TCI-P will be effective at reducing GHG emissions to the extent regional estimates have claimed. After all, the state of Maine is unique, and it may not be the case that the TCI-P functions the same here as it would in New York, Pennsylvania, or Massachusetts. In reality, the TCI-P's efficacy will depend on the price elasticity of demand for gasoline, future changes to the vehicle fleet (e.g., electrification), and how allowance auction proceeds are invested—all of which may differ in Maine as compared to the rest of the TCI-P region. Furthermore, government officials should be aware of the potential roadblocks to public acceptance of the initiative. In order to be effective, the TCI-P must remain in place for years to come. Political backlash from rising gasoline prices, a regressive tax schedule, or ill-advised investment decisions may prevent the TCI-P from having a lasting, positive impact on transportation and climate outcomes.

The factors mentioned above are all important determinants of the TCI-P's efficacy at reducing GHG emissions in Maine. This thesis focuses specifically on two of these variables: price elasticity and roadblocks for public acceptance of the TCI-P. Specifically, it examines the price elasticity of households in Maine and conducts an economic analysis of how potential increases in the price of gasoline will affect rural and urban populations. Understanding households' price elasticity provides important insights into how households' reductions in gasoline consumption and expenditures will help meet the state's emission reduction goals. It also provides an understanding of how rural and urban populations are differentially affected by the TCI-P. First, I hypothesize that the short-term price elasticity of demand for gasoline will differ substantially between rural and urban Maine. Second, I hypothesize that the TCI-P will impact these segments of the population heterogeneously. This disparity may pose challenges for public acceptance of the TCI-P.

1. Cap-and-invest Programs

The TCI-P is a cap-and-invest program. Cap-and-invest programs attach a price to carbon emissions to internalize their associated environmental costs (Burtraw, Domeshek, and Wietelman 2020). While similar to carbon taxes, cap-and-invest programs have some unique benefits, including certainty about total emission reductions and flexible price structures that are more responsive to changing economic conditions (Raymond 2019). Like other cap-and-invest programs, the TCI-P proposes auctioning off a certain number of "allowances" to Maine's fuel suppliers (Burtraw, Domeshek, and Wietelman 2020), each of which must hold allowances proportionate to the amount of fuel sold (Transportation and Climate Initiative 2019). Once auctioned, allowances can be exchanged between jurisdictions (Transportation and Climate Initiative 2020). This system allows emission reductions to be made at low cost (Burtraw, Domeshek, and Wietelman 2020), since trading will continue until the marginal abatement costs of each supplier are equalized (Field and Field 2017).[2]

1.1 Program Design

After the final Memorandum of Understanding (MOU) was released in December 2020, four jurisdictions signed the document, including Massachusetts, Rhode Island, Connecticut, and the District of Columbia (LeBlanc 2020). These jurisdictions are now working together to draft a final Model Rule (Transportation and Climate Initiative 2020), which will contain a designated emissions budget for each jurisdiction based on its relative contribution of transportation-related emissions in the TCI-P region (Transportation and Climate Initiative 2019a). Preliminary emission budget estimates can be found in the final MOU (Transportation and Climate Initiative 2020). Emission budgets correspond to a limited number of allowances that are auctioned off to fuel suppliers in each respective TCI-P jurisdiction (Transportation and Climate Initiative

[2] This is only true if the market for allowances is competitive, which it is assumed to be given the TCI-P region is comprised of hundreds of fuel suppliers. See Murphy (2019) for more information.

2020).[3] Each allowance represents one metric ton of CO_2 (Arroyo, Theoharides, et al. 2020).

As mentioned above, the TCI-P is expected to generate $2 billion in annual revenues given full participation by all 13 jurisdictions. However, only four jurisdictions have currently signed on, resulting in more modest monetary benefits (GCC 2020b). With these revenues, jurisdictions will make investments in accordance with TCI-P program goals (Transportation and Climate Initiative 2019a; 2020). The MOU restricts how investments may be used. For example, investments must at least contribute to the goals of the TCI-P program, which include reducing emissions and ensuring an equitable distribution of costs and benefits (Transportation and Climate Initiative 2019a; 2020). In general, the GCC has identified five different categories of investment options from which each jurisdiction may choose: (1) electrification of the (light-duty) vehicle fleet; (2) expansion of public transit options and accessibility; (3) expansion of low (or zero) emission heavy-duty buses and trucks; (4) improvements in system efficiency; and (5) expansion of active mobility infrastructure for pedestrians and bikers (Arroyo, Theoharides, et al. 2020; Arunachalam et al. 2020). An additional "other" category, meant to capture all other investment possibilities, is estimated to receive just 8-17% of program proceeds (Arunachalam et al. 2020).

While investment decisions are left to individual jurisdictions (Transportation and Climate Initiative 2020), the GCC has identified three specific investment portfolios that

[3] The draft MOU is very specific about what fuel and which suppliers are to be regulated. All gasoline and on-road diesel that will ultimately end up at the pump in a participating jurisdiction is considered regulated fuel under the draft MOU. As soon as said fuel is withdrawn from a terminal rack, fuel suppliers are subject to TCI-P regulations and must obtain the appropriate number of allowances (Transportation and Climate Initiative 2019a). See figure A1 in appendix A for a diagram of the gasoline supply chain.

accomplish different program goals (Arroyo, Theoharides, et al. 2020). The first portfolio, portfolio A, diversifies investments across all five categories but prioritizes active mobility infrastructure (Arunachalam et al. 2020; GCC 2020). Investment portfolio C prioritizes those investments that most reduce GHG emissions in the TCI-P region—namely the electrification of the light-duty vehicle fleet and expansion of low emission heavy-duty buses and trucks. The middle ground is investment portfolio B, which combines both investment strategies (Arroyo, Theoharides, et al. 2020; GCC 2020a; Arunachalam et al. 2020). Participating jurisdictions may use these portfolios to guide investment decisions in accordance with their own objectives.[4]

While jurisdictions determine how best to invest TCI-P proceeds, ongoing modeling efforts have sought to explore how various cap levels could impact participating jurisdictions differently. In 2019, the GCC reported potential gas price increases given a 20%, 22%, or 25% CO_2 cap reduction from 2022 to 2032 (GCC 2019). These caps were estimated to produce price increases of \$0.05, \$0.09, or \$0.17 per gallon of gasoline, respectively (GCC 2019).[5] All modeling results, including those of the present research, were based on these three cap levels. However, in December 2020, TCI-P jurisdictions agreed to delay the carbon cap until 2023 but raise the cap level to 30%,

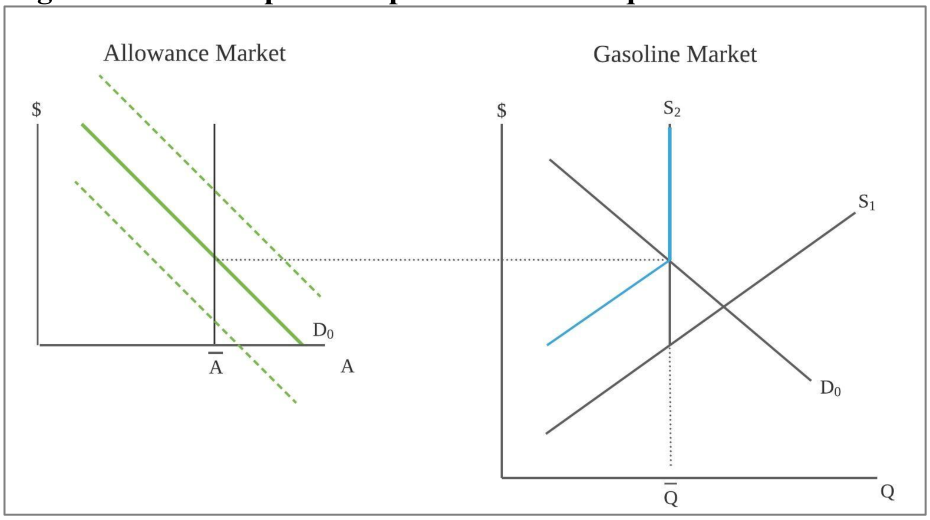
[4] It is worth noting that the more an investment reduces GHG emissions from the transportation sector, the lower the allowance price in the TCI-P region will be (GCC 2020a). This is because investments targeting GHG emissions reductions in the transportation sector will reduce the demand for gasoline. If more people drive electric vehicles, for example due to investments in rebates, the demand for gasoline will fall, easing pressure on the allowance market and lowering the price of allowances.
[5] Together with reductions in fuel demand, these price increases can generate implied elasticities of demand for motor fuel. However, this elasticity is not necessarily the same as the one the present research is attempting to estimate. For example, the estimate from the GCC report applies to economy-wide demand for motor fuel (both gasoline and diesel) (GCC 2019), whereas the present study examines the household elasticity of demand for gasoline only. It is also highly probable that these implied are measuring something else entirely, for example economy-wide responses to the cap rather than the response of individual consumers or businesses.

resulting in a 26% decline in transportation carbon emissions as opposed to a 20%, 22%, or 25% decline (GCC 2020b). Updated modeling results predicted anywhere between a \$0.05 and \$0.09 per gallon price increase depending on allowance demand (GCC 2020b). These latest modeling results also predicted carbon emissions in the transportation sector will decline by 24.3% from 2022 to 2032, regardless of jurisdictions' participation in the TCI-P (GCC 2020b). This decline, known as the "reference case," is due to an expected shift toward vehicle electrification as well as an anticipated rise in fuel economy over the coming decade (GCC 2020b). Thus, the TCI would be responsible for just 1.7 of the 26-percentage-point decline in CO_2 emissions over the 2022 to 2032 period.

In cap-and-invest settings such as the TCI-P, price stabilization mechanisms help to keep prices from rising or falling above or below established levels. As shown in figures 1, 2, and 3 below, price stabilization mechanisms are needed to prevent drastic fluctuations in the price of allowances or motor fuel. TCI-P modeling has recently focused on cost and emissions containment reserves (Arroyo, Theoharides, et al. 2020), two mechanisms that have already been incorporated in the TCI-P MOU (TCI 2020). Offsets and allowance banking are two other price stabilization mechanisms available to fuel suppliers to help stabilize prices (Transportation and Climate Initiative 2020).

Cost and emissions containment reserves are designed to stabilize prices by adding or removing allowances from circulation if prices become volatile (Transportation and Climate Initiative 2019a; Burtraw, Domeshek, and Wietelman 2020). RGGI already utilizes these mechanisms to facilitate price stabilization of allowances and electricity in

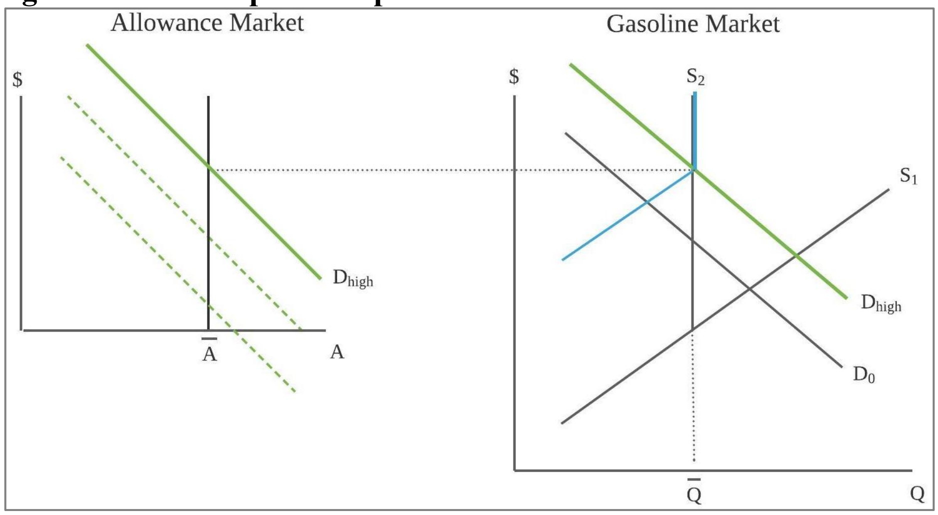
Figure 1. TCI-P cap with expected demand equal to actual demand



Note: The two graphs shown above represent the interaction of supply and demand in the markets for two goods: allowances (left) and gasoline (right). The Y axis represents the price of the good ($), and the X axis represents the quantity (Q). In the allowance market, $\bar{A}$ represents the carbon cap (set at 30% beginning in 2023), or the maximum cumulative amount of allowances available in the TCI-P region. A higher cap would be associated with a lower relative quantity of allowances and a higher relative allowance price. In the allowance and gasoline markets, D_0 represents demand in a normal year, where the expected value of D_0 is equal to actual demand. In the market for gasoline, the intersection of D_0 and S_1 represents the initial market equilibrium price and quantity before the introduction of the carbon cap. The intersection of D_0 and S_2 represents the equilibrium after the TCI-P cap, where gasoline consumption and production declines to $\bar{Q}$. The introduction of the cap means there is now a limited number of allowances available (in the absence of flexibility mechanisms). The introduction of allowances raises the cost of retail gasoline, as suppliers try to pass their costs onto consumers. Adding the allowance cost, the supply curve for gasoline shifts up from S_1 to S_2. Note that, unlike S_1, absent flexibility mechanisms, there is a kink in S_2 corresponding to the level of the cap, $\bar{Q}$.

the power sector (Arroyo, Theoharides, et al. 2020). In the case of the TCI-P, cost containment reserves (CCRs) stabilize prices by adding allowances to the market in the case of sudden, unexpected, or inordinate *increases* in demand (Arroyo, Theoharides, et al. 2020). In the absence of a CCR, the market for allowances could experience severe price increases that would have undesirable impacts on fuel suppliers and consumers. Emission containment reserves (ECRs) are the opposite of CCRs and help to keep

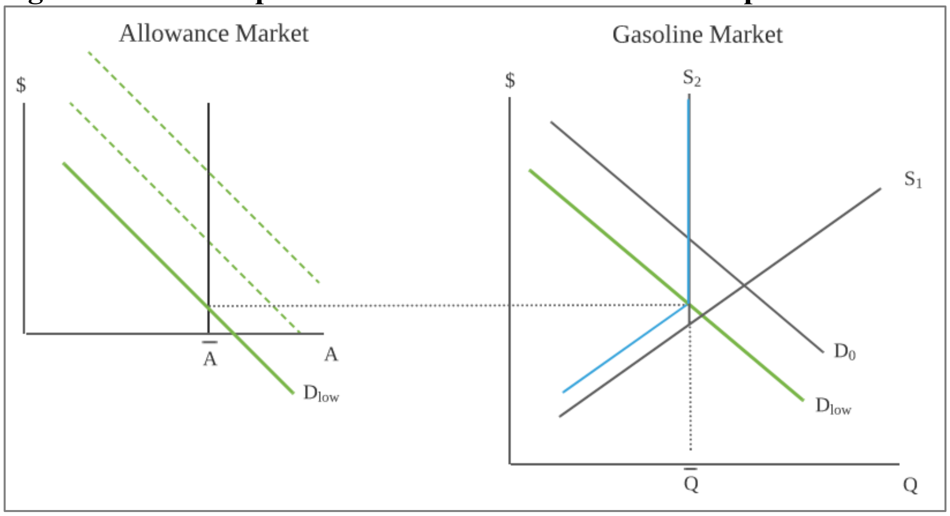
Figure 2. TCI-P cap with expected demand lower than actual demand



Note: The above graphs are the same as in figure 1, except that now the demand for gasoline is higher, represented by D_{high}.) The cap remains at $\overline{A}$, and the amount of fuel that suppliers are able to sell remains at $\overline{Q}$. At D_{high}, each fuel supplier tries to increase the quantity supplied of gasoline. In an ordinary market, the invisible hand would guide the economy to a new price and quantity where D_{high} intersects S_1. However, the TCI-P ties the gasoline market to the allowance market. Because the TCI-P cap places a limit on the number of allowances available, each fuel supplier competes with the next to obtain as many of these allowances as possible. This competitive pressure causes the price of allowances to rise. As a result, the cost of supplying fuel rises, too. S_1 shifts to S_2 by an amount proportionate to the allowance price, which is higher than it was in figure 1.

allowance prices from plummeting in the case of sudden, unexpected, or inordinate *decreases* in demand (Arroyo, Theoharides, et al. 2020). ECRs work by removing allowances from the market to further reduce emissions from the transportation sector when it is least costly to do so. Figure 4 shows how CCRs and ECRs change the shape of caps without price stabilization mechanisms, such as those shown in figures 1, 2, and 3. Note that each figure is meant to represent demand and supply over a period of three years, since the MOU stipulates three-year compliance periods (Transportation and Climate Initiative 2020). During this window, fuel suppliers are given an extended amount of time to meet allowance obligations, which serves to minimize the volatility of year-to-year fluctuations in fuel prices from high or low demand.

Figure 3. TCI-P cap with actual demand lower than expected demand

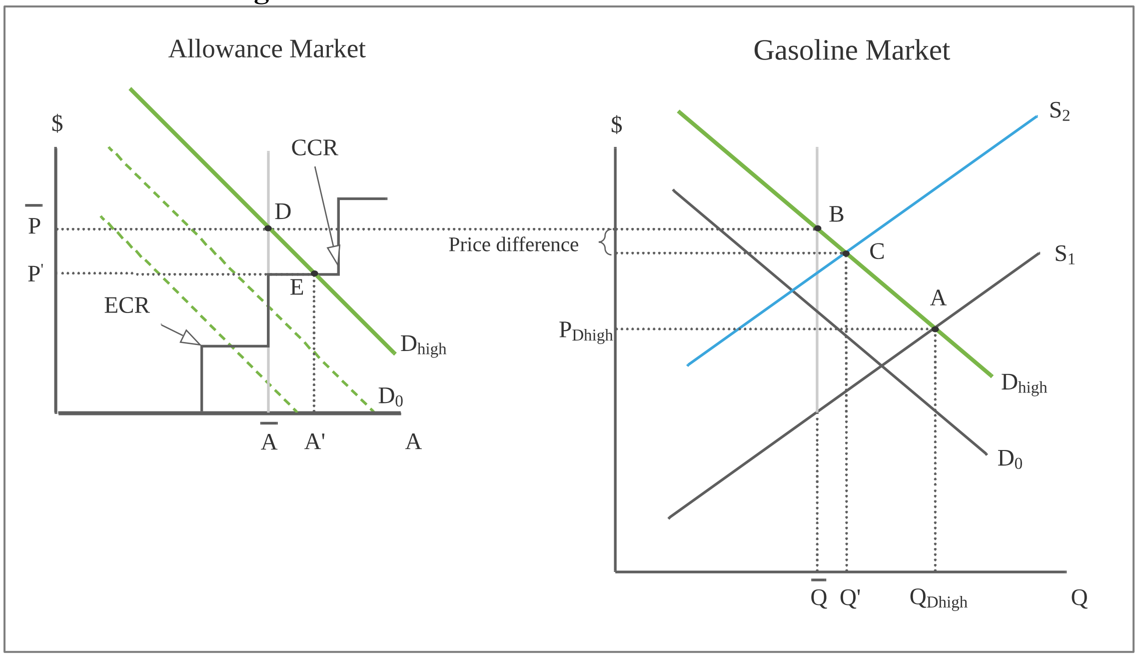


Note: The graphs above represent what could happen in a low demand year, where the demand for gasoline is D_{low}, and the supply for gasoline is S_2. Just as high demand causes the price of allowances to rise, low demand causes the price of allowances to fall, resulting in lower input costs for fuel suppliers as compared to the normal demand case in figure 1. Note that the amount of allowances/gasoline sold remains unchanged at $\overline{A}/\overline{Q}$, while the price of allowances/gasoline falls compared to figures 1 and 2.

The actual threshold (or "trigger price") at which CCRs/ECRs will release/remove allowances is still being debated by TCI-P designers but may be determined along with the final Model Rule. Once the allowance market becomes volatile enough to trigger the CCR or ECR, questions remain about how many allowances should be added or removed to stabilize prices. Preliminary estimates suggest an appropriate reserve size would average 10% of the overall carbon cap by the end of the 2023-2032 period (Arroyo, Theoharides, et al. 2020).[6] In other words, if the 30% cap were to reduce emissions from 260 metric tons of CO_2 ($MTCO_2$) in 2023 to 182 $MTCO_2$ in 2032 (an average of 7.8 $MTCO_2$ per year), an additional $\frac{(260+182)}{2} * 0.1 = 22.1$ $MTCO_2$ could be released on average to help stabilize prices. The converse would hold for the proposed ECR.

[6] The reserve size for RGGI is also 10% of the cap (GCC 2020a).

Figure 4. Cost and emissions containment reserves



Note: The solid green demand curves represent high demand in the gasoline and allowance markets. The vertical pale grey line represents what would occur given the absence of price stabilization mechanisms; it is the cap without CCRs and ECRs shown in figures 1, 2, and 3. Adding CCRs and ECRs creates a "stepped" cap whereby allowances are added or removed depending on the allowance price. Where the demand curves intersect the stepped cap represents the number of allowances, and therefore gallons of gasoline, that can be bought and sold. Imagine that the quantity of gasoline bought and sold is initially at point A on the right-hand graph. At this point, there is no TCI-P and therefore no allowance market. Quantity demanded of gasoline is Q_{Dhigh} and price is P_{Dhigh}. Now imagine an allowance market is introduced, as depicted in figures 1, 2, and 3. At D_{high}, the price rises from P_{Dhigh} to the dashed line intersecting point B on the right-hand graph. At this point, the price of allowances is $\bar{P}$, and the quantity of allowances is $\bar{A}$, as marked by point D on the left-hand graph. Once the cost containment reserve is implemented, however, the stepped cap causes the price of allowances to fall to P' and the number of allowances to increase to A', as marked by point E on the left-hand graph. Note what happens to the quantity of gasoline sold, which rises from $\bar{Q}$ to Q'. The price of gasoline also falls by the vertical distance from point B to point C. While not shown on the above graphs, emissions containment reserves have the opposite effect of inflating the price of allowances by removing them from the market in cases of low demand, represented by the bottom-most dashed demand curve in the left-hand graph.

Offsets and allowance banking are two additional price stabilization mechanisms included in the MOU. Offsets can stabilize prices by easing demand for allowances at a time when market demand for motor fuel is especially high. Specifically, fuel suppliers can engage in less expensive but proportional mitigation strategies rather than purchasing additional allowances. Although the TCI-P will allow offsets as a potential price stabilization mechanism, the MOU has specified that their use must be limited (Transportation and Climate Initiative 2020).[7] Finally, banking is another price stabilization mechanism that can stabilize prices by allowing fuel suppliers to store allowances when demand is low and draw from these stores when demand is high. The TCI-P would permit fuel suppliers to bank allowances indefinitely (Transportation and Climate Initiative 2020).

1.2 Program Benefits

Aside from the immediate benefits of these investments, proceeds from allowance auctions would also contribute to long-term goals surrounding public health, equity, GDP, jobs, and climate change. The public health benefits of the TCI-P program are significant. Research from the Transportation, Equity, Climate, and Health (TRECH) project, led by the Harvard T.H. Chan School of Public Health's C-Change Center for Climate, Health, and the Global Environment, showed that monetized benefits to health from increased walking and biking could be as high as $1.8 billion in 2032, assuming jurisdictions follow investment portfolio B (Arunachalam et al. 2020).[8] These benefits come largely from avoided deaths and reduced cases of childhood asthma (Arunachalam et al. 2020). Other public health benefits from the TCI-P include reductions in volatile organic compounds (VOCs), nitrogen oxides (NOx), ammonia (NH_3), sulfur dioxides

[7] Certain types of offsets, such as reforestation, have received some criticism for being impermanent. See section "Why carbon offsets don't work" in chapter 9 of Peter Kalmus' *Being the Change: Live Well and Spark a Climate Revolution* (2017). However, offsets that are real, permanent, additional, verifiable, and enforceable are generally considered effective (Goodward and Kelly 2010).

[8] This estimate is based on outdated modeling from 2019 and assumes a 20% cap reduction (Arunachalam et a. 2020). The GCC (2020b) claimed that this scenario is the most indicative of benefits expected given the latest modeling results, but it is uncertain just how indicative it is. Furthermore, results assume jurisdictions will invest 90% of auction proceeds in low-carbon transportation (Georgetown Climate Center 2020b), which may not be practicable given the MOU mandate that 35% of investments be dedicated to underserved and overburdened communities (Transportation and Climate Initiative 2020).

(SO_2), and particulate matter (Arunachalam et al. 2020). Improved air quality from the TCI-P is estimated to result in approximately 80 avoided deaths in the year 2032 (Georgetown Climate Center 2020b). All results assume full participation of the 13 jurisdictions in the TCI-P region (GCC 2020b).

These reductions are expected to mitigate some of the historical inequity faced by marginalized and disadvantaged communities. TRECH found that, historically, ethnic minorities, the poor, and the uneducated have been adversely and disproportionately affected by air pollution (Arunachalam et al. 2020). The TCI-P would therefore bring benefits in air pollution reductions to these communities that would help counterbalance this historical inequity (Arunachalam et al. 2020).[9] Since its inception, the TCI-P has emphasized the importance of mitigating inequity, and this principle is embodied in the MOU (Transportation and Climate Initiative 2019a). In fact, the MOU mandates that 35% of auction proceeds be invested in ensuring the equitable distribution of costs and benefits for the most economically burdened communities of the TCI-P region (Arroyo, Miller-Travis, et al. 2020).

Importantly, almost none of the benefits of reduced air pollution will accrue to Mainers. For example, reduced mortality benefits are concentrated in more urban jurisdictions such as New York, Massachusetts, New Jersey, and Pennsylvania (see figure 3 of Arunachalam et al. (2020)), as are reductions in childhood asthma (see figure 4 of Arunachalam et al. (2020)). It is likely that few of the benefits of increased active mobility infrastructure would accrue to Mainers, either, due to the state's cool climate

[9] Results are reported assuming a 25% cap, and, as was already stated above, only results for the 20% cap are expected to somewhat resemble conditions under the latest TCI-P modeling results. Therefore, this equitable outcome may not apply to the same degree as under a 25% cap.

and rural landscape. To measure active mobility benefits, the TRECH project used the World Health Organization's Health and Economic Assessment Tool (HEAT), which is better suited for urban areas where trips are more likely to be within walking or biking distance. According to Kahlmeier et al. (2017), "HEAT aims to promote the integration of the economic value to society of reduced premature mortality from cycling and walking into the economic appraisal of transport and *urban planning and interventions*," (Kahlmeier et al. 2017, 21; my emphasis). The HEAT model likely should not be construed to represent the TCI-P's more rural jurisdictions, including Maine.

In addition to health and equity benefits, investments from TCI-P proceeds are expected to create net growth in GDP, increase jobs, and lower climate impacts. The latest estimates predict an annual GDP growth of approximately $97 million for the four participating jurisdictions (GCC 2020b). In addition, the GCC reported that the TCI-P could create approximately 434 jobs annually and boost disposable personal incomes by $75 million each year from 2023 to 2040 (Arroyo, Theoharides, et al. 2020). Again, these estimates hold only for the four participants of the TCI-P.[10,11]

1.3 The Relevance of Price Elasticity

Should Maine become a signatory to the TCI-P, the extent to which GHG emissions decline will depend in part on Mainers' price elasticity of demand for gasoline.

[10] It is important to keep in mind that many health and climate benefits will accrue to the TCI-P region regardless of whether jurisdictions participate in the program or not. This is because of the reference case scenario where transportation-related emissions are expected to decline by 24.3% from 2022 to 2032 even without the TCI-P.

[11] TRECH results have not been peer reviewed.

Table 1. Elasticity ranges

Perfectly inelastic	Inelastic	Unit Elastic	Elastic	Perfectly Elastic
$\eta = 0$	$0 > \eta < 1$	$\eta = 1$	$\eta > 1$	$\eta = \infty$

Note: In absolute value, elasticity estimates range from 0 to ∞. The Greek letter Eta (η) is also the symbol for elasticity.

Mainers make decisions every day about how often and how far to drive, and the price of gasoline is one important determinant of these decisions. Price elasticity represents the sensitivity, in terms of quantity demanded, to changes in the price of a good or service. In the market for gasoline, for example, it answers the question, “How will gasoline consumption change given a unit change in price?” Since the TCI-P is estimated to raise gasoline prices by the amounts given above, price elasticity estimates give a sense of how much gasoline consumption is expected to fall as a result. In absolute value, the higher the elasticity estimate, the more “elastic” (or the more “sensitive”) is one’s demand. Elasticities can be divided into 5 categories, as shown in table 1 above. Historically, short-run estimates of the price elasticity of demand for gasoline often fall between -0.2 and -0.3, and long-run estimates often fall between -0.6 and approximately -0.8 (Ajanovic, Dahl, and Schipper 2012; Basso and Oum 2007; Graham and Glaister 2002). This means that, in the short run, a 10% increase in the price of gasoline would produce a 2.5% decrease in the quantity demanded, and in the long-run it would produce a 7.5% decrease. Note that both short- and long-run estimates are inelastic, but that price elasticity in the long-run is more elastic than in the short-run.

While many estimates do tend to fall within this range, valid elasticity estimates have deviated from these ranges—and oftentimes for good reason. Havranek, Irsova, and Janda (2012), for example, found publication bias in the literature and predicted that more accurate short- and long-run estimates are -0.09 and -0.31, respectively. In contrast, Spiller, Stephens, and Chen (2017) found a mean short-run estimate (for households) of -0.74, and Wadud, Graham, and Noland (2010) found an intermediate-run estimate (for households) of -0.47. The difference between short-, intermediate-, and long-run estimates will be discussed more below, but for now it is important to simply note the disagreement among various estimates in the literature.

Various authors have given reasons for this disagreement (Basso and Oum 2007; Hughes, Knittel, and Sperling 2008; Dahl 2012; Graham and Glaister 2002). Basso and Oum (2007), for example, explained that economists use very different approaches when it comes to estimating something as simple as the price elasticity of demand for gasoline, ranging from different types of econometric models to different sources of data. There are at least four main reasons for variations in elasticity estimates. The first is the time horizon that the estimate is meant to represent. Some models produce short-run elasticities, while others produce intermediate- or long-run elasticities. Economists have for years attempted to distinguish between these time horizons and their different effects on consumer behavior. It is assumed that in the short-run (approximately 1 to 5 years), consumers do not have enough time to fully adjust their behavior to changes in price. For example, if the price of gasoline suddenly rises by $0.50 per gallon, I cannot simply begin driving less; I have an obligation to my employer to continue showing up to work, and I have an obligation to my children to continue picking them up from school. There may be minor adjustments I can make to my driving behavior, such as using my coupe instead of my SUV to visit the grocery store (Brons et al. 2007), but in general I will not be able to reduce my fuel use until sufficient time has passed and I have made adjustments to my living situation or else found a job closer to home. In this way, economists expect the price elasticity of demand for gasoline to be more elastic in the long-run than in the short-run. Indeed, on average, this is what the data shows—but it is important to note that, as econometric practices and methodologies have developed over time, economists have contemplated how best to interpret the time frame of certain model-data combinations (Dahl 2012; Basso and Oum 2007). In other words, it has not always been certain which time-frame elasticity estimates are meant to represent.

The time horizon of elasticities partially accounts for the variation in economists' estimates, but there are at least three other explanations. One is that the price elasticity of demand for gasoline may have actually changed over time. Hughes, Knittel, and Sperling (2008) found that the price elasticity of demand for gasoline is significantly less elastic today than it was in the 1970s and 1980s, for which they provided two explanations. The first is that suburban developments have expanded rapidly over time, leading to longer commute times and less flexibility in gasoline consumption decisions (2008). The second is that incomes have risen faster than gasoline prices and therefore gasoline does not make up as big a percentage of household budgets as in previous decades (Hughes, Knittel, and Sperling 2008). In this sense, households do not reduce gasoline consumption much in response to an increase in price. It is of course important to note here that the second explanation works against the first, since driving more miles equates to allocating a *greater* share of one's household budget to gasoline. Still, the suggestion that price elasticities can change over time is a valuable one and should be kept in mind as TCI-P modeling continues.

Another explanation for variability in elasticity estimates is the use of different types of econometric models. Basso and Oum (2007) presented a comprehensive list of various types of models used to calculate elasticities. These include reduced-form demand models (static or dynamic), co-integration and error correction models, and structural models (2007). Each model has advantages and disadvantages, revealing unique characteristics of fuel demand that others cannot (2007). Still, different econometric models produce different elasticity estimates, so it is important to be cognizant of which is being presented before drawing conclusions.

Closely related to the type of model is the form of data. Data can vary in at least three respects: (1) according to type (cross-sectional, time-series, or cross-sectional time-series), (2) according to origin (country/region the data is from), and (3) according to source (aggregate or household-level data). Not surprisingly, the kind of data used can produce significantly different elasticity estimates. For example, for the same reduced-form demand model and regardless of the time horizon of the estimate, studies using cross-sectional data generate higher elasticity estimates (Basso and Oum 2007). Dahl (2012) also found that studies using cross-sectional data generated higher price elasticity estimates than studies using time-series data. The location of the data is also crucial, as Dahl (2012) found global, intermediate-term elasticity estimates ranged anywhere from -0.04 to -0.69 depending on the country. Differences in price elasticity estimates also arise when data is drawn from different sources. Estimates that use aggregate-level data collect price and quantity information from the economy as a whole, including commercial vehicles. In contrast, household-level data (mostly) excludes information on commercial vehicles and focuses on economic decisions made by the average consumer (Basso and Oum 2007; Graham and Glaister 2002). Since studies using household data give more elastic estimates than studies using aggregate data, Wadud, Graham, and Noland (2010) believed that the inclusion of commercial vehicles, which are less sensitive to changes in the price of gasoline, distort households' true sensitivity to changes in the price of gasoline.

In summary, estimates of the price elasticity of demand for gasoline can vary for four main reasons: (1) the time horizon inferred, (2) the advancement of society, (3) the econometric model used, and (4) the kind of data used. This diversity in elasticity estimates raises questions over the appropriate estimate to use in the present research. Since this thesis focuses exclusively on the effects of the TCI-P on the state of Maine, it is imperative to ensure the estimate accurately reflects Maine-specific demographics. A household data study by Spiller, Stephens, and Chen (2017) allows for this customization, making it the best candidate for the present research. While elasticity estimates using household data tend to be higher than average, the authors' model can provide a robust understanding of how individual households might respond to the TCI-P.

1.4 The Heterogeneous Effects of Changes in the Price of Gasoline

Given the type of data selected as well as the policy focus of my thesis, it is important to examine how households may respond differently to changes in the price of gasoline, which has implications for how different households are affected in terms of the associated economic loss and burden of a price change. This is what is meant by the term "heterogeneous effects." That price changes affect people in different ways is well documented in the literature (Wadud, Graham, and Noland 2010; Basso and Oum 2007; Spiller, Stephens, and Chen 2017). Such heterogeneity has policy implications if it influences how policymakers choose to invest proceeds from the auctioning of allowances. There are at least three factors at play in the heterogeneous effects of price changes: (1) a household's price elasticity of demand, (2) household income, and (3) VMT.

A household's price elasticity can vary for a number of reasons, including its distance from a metropolitan statistical area (MSA), the number of vehicles owned, average commute time, income, number of cars, and location (urban or rural), among other things (Basso and Oum 2007; Wadud, Graham, and Noland 2010; Spiller, Stephens, and Chen 2017). The way in which households are disproportionately affected has to do with their consumer surplus from gasoline consumption. Consumer surplus (CS) is an economic concept describing the excess benefit a consumer receives from purchasing a given quantity of a good or service at a given price. For example, if I value a cup of coffee at \$5 but a nearby café only charges me \$2, my CS for the first unit is \$3 (\$5 – \$2 = \$3). If I value the second cup of coffee at just \$4, my CS for the second unit is \$2 (\$4 – \$2 = \$2). The total CS is found by summing the CSs for each unit over all units purchased. In this way, CS can be viewed as a measure of welfare. Therefore, a consumer's wellbeing can be said to decline if their CS declines, for example, through an increase in price. As outlined above, consumers with a relatively elastic demand for a good adjust their quantity much more than consumers with a relatively inelastic demand for a good, and therefore their CS declines in greater proportion for a given change in price. Households with multiple vehicles (especially if they are fuel efficient), multiple wage earners, and higher incomes tend to have more elastic responses to changes in the price of gasoline and therefore are prone to experiencing the greatest welfare loss (Spiller, Stephens, and Chen 2017). The literature does not provide a clear answer to whether rural households have higher or lower elasticities than households located in urban areas.

Heterogeneous effects also depend on household income. For example, a given change in the price of gasoline is likely to affect poor households more than wealthy households as a proportion of income, even if their elasticities are identical (they are not). Spiller, Stephens, and Chen (2017) estimated that the poorer the household, the less elastic response to changes in price. This implies it may be more difficult for them to compensate for price increases by lowering demand. In fact, multiple authors have noted that gasoline taxes (and therefore cap-and-invest programs such as the TCI-P) are regressive, meaning that, as a proportion of household income, they affect poor households the most (Wadud, Graham, and Noland 2010; Spiller, Stephens, and Chen 2017).

Heterogeneous effects can also arise through differences in vehicle miles traveled (VMT) on a day-to-day basis. *Ceteris paribus*, any household that travels greater distances must consume more gasoline and will therefore be disproportionately impacted by a cap-and-invest program such as the TCI-P. Rural households, in particular, fall into this category (Basso and Oum 2007; Spiller, Stephens, and Chen 2017; Wadud, Graham, and Noland 2010).

In summary, the various factors discussed above will play a role in determining how Mainers are impacted if the TCI-P is adopted. Whether Maine experiences a relatively large welfare loss compared to other states will depend on its average price elasticity, but the total economic burden may depend more on income and VMT (Spiller, Stephens, and Chen 2017). Not only is Maine poorer than all other states in the TCI-P region (United States Census Bureau 2018), it is also exceedingly rural. Because of Maine's unique demographics, gathering input from the public and considering various investment strategies to mitigate some of these heterogeneous effects will be important steps for officials in crafting future messaging and communication strategies.

1.5 Public Opinion on the TCI-P

As work on the TCI-P progresses, jurisdictions have continued to seek input from the public. In fact, since the draft MOU was released in 2019, over 3,000 comments have been submitted to the TCI-P for review by the fossil fuel industry, nongovernmental organizations, labor unions, faith leaders, equity and environmental justice groups, and others (Arroyo, Miller-Travis, et al. 2020). In Maine, public comments have largely taken the form of letters submitted to the co-chairs of the TWG of the MCC, Joyce Taylor and Sarah Cushman. These letters revealed mixed support for the TCI-P in Maine: while some organizations opposed the adoption of the TCI-P on the grounds that it would harm industry, others supported its adoption, saying it is one of the best (or only) ways to ensure a decline in GHG emissions. Still others made recommendations for how TCI-P proceeds should be reinvested in Maine's economy. If the diversity of these letters suggests one thing, it is that the TCI-P will impact Mainers differently.

Public support for the TCI-P revolves around several main areas. In May of 2020, Jeff Marks, representing a coalition of 28 organizations such as Acadia Center and Sierra Club Maine, wrote to the co-chairs of the TWG in support of the TCI-P. He argued that there is already some precedent for the program in RGGI and that the TCI-P would be a guaranteed source of emissions reductions. Mark Brown, from the Washington County Coalition of Environmental Groups, also wrote a letter stating that climate change poses a serious threat to Maine industries and businesses and therefore that any effort to curb emissions is a valid one. Georgia Murray from the Appalachian Mountain Club expressed similar views in her letter, while Marks expressed approval of the TCI-P's focus on equity. These organizations are not the only entities to have expressed support for the TCI-P: a recent survey from Climate Nexus and the Yale Program on Climate Change Communication (YPCCC) showed at least some support for the TCI-P among 56% of Maine respondents (Climate Nexus and YPCCC 2020).[12] This is compared to 26% of respondents that were at least somewhat opposed to the TCI-P and 18% that were uncertain (Climate Nexus and YPCCC 2020).

While many Maine citizens and organizations support the TCI-P, the trucking and logging industries have expressed strong opposition. Dana Doran, representing the Professional Logging Contractors of Maine (PLC), wrote the TWG to express his concern that the TCI-P would place an unbearable cost burden on the logging industry in the state. Similar concerns were raised by Paul Towle, who wrote the TWG representing 75 businesses in the Aroostook Partnership. Towle argued that the TCI-P would hit the trucking industry particularly hard since trucks must drive long distances through rural parts of the state. He further stated that the trucking industry operates on thin profit margins as it is, and that the TCI-P could severely impact agriculture and forestry as products would be transported long distances at higher cost. Towle also expressed concern over how the TCI-P may disproportionally impact low-income families that

[12] The Climate Nexus and YPCC survey used a multilevel modeling poststratification (MRP) method to conduct a scientific poll of registered voters across all TCI states, including Maine. The survey uses a credibility interval of 95% (+/- 1.6%) rather than the traditional margin of sampling error (MOE). The American Association for Public Opinion Research (AAPOR), a leading authority in the field, cautions against the use of credibility intervals due to the greater potential for faulty assumptions (Santos, Buskirk, and Gelman 2012). See pages 16 through 18 in Climate Nexus and YPCC (2020) for more information on polling methodology.

cannot switch to public transportation because it simply does not exist in parts of rural Aroostook County. Furthermore, Towle claimed that efforts to bring public transportation to the area in the past had failed because it was prohibitively expensive. Towle also raised concerns that fuel costs for snowplows and school buses would rise after the TCI-P, which would create a greater burden on state/municipal governments and therefore taxpayers. He therefore concluded that the TCI-P is not an equitable program and that it would inevitably impact rural communities more than urban ones.

Regardless of support or opposition to the TCI-P, Mainers have expressed preferences for investments should Maine become a signatory. Preferences center around low-emissions transportation options and rebates for more fuel-efficient vehicles. For example, Brown wanted the state to invest in low-emission public transportation, while the East Coast Greenway Alliance and the Appalachian Mountain Club advocated for investments in walking or biking paths/lanes. According to the Climate Nexus survey, 78% of respondents expressed at least some support for using TCI revenues to expand public transportation routes to rural and suburban locations without a public transportation option (Climate Nexus and YPCCC 2020). Similarly, 82% of respondents expressed at least some support for expanding sidewalks should the TCI be adopted in Maine, and 64% expressed at least some support for adding bike lanes (Climate Nexus and YPCCC 2020). Finally, 72% of respondents said they would like to receive rebates for purchasing more fuel-efficient vehicles if the TCI-P is ratified in Maine.

Public comments and opinion polling show that Maine's views of the TCI-P are mixed. Many view the program as a vital component of ongoing efforts to curb climate-warming emissions as well as an important source of revenue, while others view the program as a threat to the welfare of rural communities and industries. If the TCI-P is eventually adopted in Maine, it is clear that investments must be cognizant of the consequences (good or bad) for all members of the population.

1.6 Objectives

My research objectives are as follows: (1) to select and adapt an elasticity estimate for rural and urban Maine households, (2) to conduct a sensitivity analysis, (3) to calculate the expected short-term change in households' CO_2 emissions from the TCI-P, (4) to determine the TCI-P's effects on state and federal tax revenues, (5) to analyze the heterogeneous impacts of the TCI-P on rural versus urban households, (6) to determine potential roadblocks to public acceptance of the TCI-P, and (7) to address these roadblocks through recommendations for investment, messaging, and communication strategies.

CHAPTER 2

METHODS

2. Data Collection

Data was collected from a variety of sources. Demographic data was obtained from the American Community Surveys and the U.S. Census Bureau, and location coordinates were found using Google Maps. Information on metropolitan statistical areas (MSAs) in Maine was retrieved from a report by the Executive Office of the President's Office of Management and Budget. Household consumption data was retrieved from a Maine Department of Environmental Protection (MeDEP) database. To convert consumption data into carbon emissions, I calculated an emissions factor using data from the Transportation Energy Data Book, compiled by the Oak Ridge National Laboratory. Information on the vehicle fleet was obtained from the Bureau of Motor Vehicles (BMV) and the Maine Department of Transportation (MeDOT). Gasoline prices for 2017 were retrieved from a gas price index from the American Automobile Association (AAA). Finally, the costs of driving in Maine were determined using data from a 2019 AAA brochure, and the age of Maine's vehicle fleet was obtained from a report by the Alliance of Automobile Manufacturers.

2.1 Selecting and Adapting Elasticity Estimates

My review of the literature suggests estimates from studies using household data are the most appropriate for determining Mainers' price elasticity of demand for gasoline. These studies tend to generate heterogeneous elasticity estimates across various household characteristics (e.g., income, number of vehicles, location, etc.). Therefore, a benefit of using this type of estimate is that it allows for the substitution of Maine-specific demographic data and thus a more fitting elasticity estimate for Maine households. In this thesis, I used an elasticity function from Spiller, Stephens, and Chen (2017) and plugged in Maine-specific estimates for each household characteristic to get an elasticity estimate right for Maine. See table B1 in appendix B for a list of the authors' elasticity estimates by household characteristic.

The estimates given by Spiller, Stephens, and Chen (2017) represent a short-term time horizon. Thus, the estimates are only valid for estimating changes in price or quantity for a 1- to approximately 5-year time horizon, in which households do not change vehicles. The model used by Spiller, Stephens, and Chen (2017) accounts for 8 different household characteristics: (1) household size, (2) vehicles per household, (3) vehicle fuel economy, (4) distance to the nearest MSA, (5) the price of gasoline faced by the household, (6) the household's average commute time, (7) income, and (8) whether or not the household is rural or urban. In order to better customize Maine's elasticity estimate, I found Maine-specific data for each characteristic and further stratified the data according to whether it came from rural or urban Maine, whenever possible.[13] I sought to generate three different elasticity estimates: one for Maine households, a second for urban Maine households, and a third for rural Maine households.

[13] The number of vehicles per household, the price of gasoline, and the average miles per gallon (MPG) were held constant for rural and urban Maine. There is good reason to believe that the number of vehicles a household owns does not differ significantly from county to county. While the MPG of these vehicles may differ, the most accurate way to estimate MPG did not allow for estimation on a county by county basis. The price of gasoline also differs from county to county, but data was again limited to state averages.

For all three elasticity estimates, the average household size, commute, and median income data were retrieved from the ACS 5-year estimates for 2014-2018 at the county level. For the urban and rural elasticity estimates, these data were weighted according to county population. County classifications as rural or urban were determined based on definitions from the United States Census Bureau. The U.S. Census Bureau defines “urban areas” as being comprised of either “urbanized areas” or “urban clusters,” where the former must have a minimum population of 50,000 people, and the latter must have a population between 2,500 and 49,999 people (United States Census Bureau n.d., par. 4). Rural areas are defined as “any population, housing, or territory NOT in an urban area,” (United States Census Bureau n.d.). According to these definitions, Maine has just three urbanized areas: Portland, Lewiston-Auburn, and Bangor (United States Census Bureau n.d.). These areas roughly correspond to Maine’s three Metropolitan Statistical Areas (MSAs): Portland-South Portland, Lewiston-Auburn, and Bangor (Donovan 2015). Each MSA contains principal cities, which in this case are the namesakes of each MSA: Portland, South Portland, Lewiston, Auburn, and Bangor (Donovan 2015). For the purpose of the present analysis, I considered as urban any county that contains the principal cities of Maine’s three MSAs. Counties classified as urban include: (1) Androscoggin, (2) Cumberland, and (3) Penobscot. Counties classified as rural include: (1) Aroostook, (2) Franklin, (3) Hancock, (4) Kennebec, (5) Knox, (6) Lincoln, (7) Oxford, (8) Piscataquis, (9) Sagadahoc, (10) Somerset, (11) Waldo, (12) Washington, and (13) York. While several of these rural counties include urban clusters such as Augusta and Waterville in Kennebec county (United States Census Bureau n.d.), these were not considered substantial enough to classify the county as being urban. This method is not perfect, but given the dearth of municipal-level data for the household characteristics described above, I determined this was the most precise way to distinguish between urban and rural Maine.

The number of vehicles per household was calculated by dividing the total number of registered household vehicles in Maine in 2017 by the number of households from the United States Census Bureau's American Community Survey (ACS) 5-year estimates for 2014-2018. The total number of registered household vehicles in 2017 was 1,145,996 (Bureau of Motor Vehicles 2017b),[14] and the total number of households was 556,955 (United States Census Bureau n.d.), for a total of 2.06 vehicles per household.

The average MPG of the Maine vehicle fleet for 2017 was calculated using VMT data from the Maine Department of Transportation (DOT). In 2015, the DOT estimated the average Mainer drives 13,500 miles per year (Maine DOT 2015). (Using a different VMT figure results in a different estimate of the fuel economy for household vehicles in Maine, as shown below.) In 2017 there were 965,674 "Class C" or "Motorcycle only" licensed drivers in Maine (Bureau of Motor Vehicles 2017a).[15] According to the Bureau of Motor Vehicles' Motorist Handbook and Study Guide, Maine offers three classes of driver's licenses. Class C is the only class for which households are eligible to apply,

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[14] Vehicle registration information by class code and plate type is available to the public. Plate types contained in the 1,145,996 total include: antique vehicles, custom vehicles, disability special veteran, disabled veteran, disabled, gold star family, island use vehicle, lobster, agriculture (passenger), low-speed, motorcycle, antique motorcycle, motorcycle disabled, disabled veteran motorcycle, passenger car, purple heart, purple heart motorcycle, prisoner of war, conservation specialty plate, black bear specialty plate, breast cancer support, street rod, sportsman, animal welfare, University of Maine System, support your troops, specialty veteran motorcycle, veteran, disabled veteran parking, Wabanaki, pearl harbor survivor, medal of honor, farm, and conservation disabled. Plate types excluded from the 1,145,996 total include: agriculture (commercial), agriculture (farm), emergency vehicles, apportioned vehicles, buses, conservation (commercial), municipal vehicles, conservation trailer, combination, commercial, county sheriff, firefighter, horseless carriage, lobster (commercial), motor home, moped, conservation motor home, special equipment, state vehicle, truck camper, trailer, tractor, tractor trailer, and hire.

[15] Since there were approximately 556,955 households in Maine in 2017 (United States Census Bureau n.d.), this figures to approximately 1.73 Class C or Motorcycle licensed drivers per household.

since Classes A and B are for commercial use only (Bureau of Motor Vehicles n.d.). Using this information, and holding VMT constant at 2015 levels, I calculated the total VMT for households in 2017 to be 13,036,599,000 miles by multiplying 13,500 by the number of licensed Class C and motorcycle drivers. To determine the amount of motor fuel purchased by households in 2017, I used a database from the MeDEP that contained consumption data for gallons of gasohol (E10) and diesel.[16] The database contained fuel consumption data on various vehicle types, including combination long-haul trucks, combination short-haul trucks, intercity buses, light commercial trucks, motor homes, refuse trucks, school buses, single-unit long-haul trucks, single-unit short-haul trucks, transit buses, motorcycles, passenger trucks, and passenger cars. Consumption data on all vehicle types except motorcycles, passenger trucks, and passenger cars was excluded since the aim was to determine the average MPG of household vehicles only. According to the MeDEP database, households consumed approximately 10,491,038 gallons of diesel fuel and 588,596,528 gallons of E10 in 2017, for a total of 599,087,566 gallons of motor fuel. To calculate the fuel economy of Maine household vehicles in 2017, I divided total VMT by the total gallons of motor fuel (gasohol and diesel combined) consumed, for a total of 21.8 MPG. The national average fuel economy for light-duty vehicles in 2017 was approximately 22.3 MPG, only marginally more efficient (Bureau of Transportation Statistics n.d.). Given that the median income for Maine is below the national average, it would be reasonable to assume that Maine has a slower vehicle turnover rate than the rest of the country. However, this is not necessarily observed in the data. The Alliance of Automobile Manufacturers, using data from IHS Markit, estimated

[16] E10 is Maine's ethanol fuel mixture; gasoline purchased at the pump is composed of 10% ethanol and 90% gasoline.

that the average vehicle age in Maine in 2018 was 11.2 years, compared to a national average vehicle age of 11.6 years (Auto Alliance n.d.). It is possible, therefore, that Maine's lower-than-average fuel economy of 21.8 MPG is instead explained by a difference in fleet composition (i.e., a higher proportion of light-duty trucks than most other states).

Fuel economy can be calculated another way, using a different estimate for annual VMT in Maine. In December of 2020, the MCC released its four-year plan for climate action (hereafter "the Plan"). The Plan contained a VMT estimate of 12,000 miles per vehicle per year (MCC 2020), as opposed to the Maine DOT estimate of 13,500 miles per person per year. To calculate a household's annual VMT from this figure, I multiplied 12,000 by the number of vehicles per household (which figures to be 2.06), for an annual household VMT of 24,720 miles. Note that the Maine DOT estimate results in a lower annual household VMT. This is because there were approximately 1.73 licensed drivers per household in Maine in 2017 (calculated by dividing the number of class C and motorcycle licenses by the number of Maine households, mentioned above to be 965,674 and 556,955, respectively). This results in an annual household VMT of 23,407 miles, which is less than the 24,720 miles per household mentioned above. Multiplying the latter value by the number of households in Maine and dividing by the total number of gallons of motor fuel results in a fuel economy estimate of approximately 23.0 MPG. This estimate is higher than the national average fuel economy in 2017 of 22.3 MPG, a peculiar result that contradicts both the income and fleet composition arguments mentioned in the previous paragraph. For these reasons, I have opted for the first method and have applied a fuel economy of 21.8 MPG for all relevant calculations.

Distance to the nearest MSA was calculated using the centers of population coordinates for Maine's 16 counties (United States Census Bureau 2010). Coordinates were entered into Google Maps and the nearest nominal location was selected. The distance from these locations to the principal city/cities of the nearest MSA was also determined using Google Maps and corresponded to the quickest route by motor vehicle. MSAs in Canada were excluded on the assumption that not every Mainer has an active passport. The distance from the centers of population for each county to the nearest principal city/cities was weighted according to each county's population data, which was retrieved from the United States Census Bureau's ACS 2019 1-year estimates (United States Census Bureau n.d.). Statewide gasoline price averages for 2017 were found using AAA's gasoline price index (AAA 2017).

After the necessary estimates for the various household characteristics were obtained, each estimate was compared to those given by Spiller, Stephens, and Chen (2017) in table B1 (see appendix B). The absolute value of the difference between these estimates was then used to determine how much, and in which direction, elasticity estimates would be adjusted. For example, if a household size of 1.5 corresponded to an elasticity of -0.679 in table B1, and if the average household size in Maine was 2.33, the adapted elasticity estimate would be adjusted upwards by the appropriate amount (in this case to -0.77). This process was followed for each elasticity estimate in Maine, as well as for the rural and urban parts of the state. See tables C1, C2, and C3 in appendix C for more information on mathematical calculations for each household characteristic. For a link to the excel file containing all the relevant calculations for this thesis, see appendix D.

2.2 Sensitivity Analysis

Sensitivity analyses help determine the importance of one elasticity estimate over another in terms of overall reductions in CO_2 emissions. In other words, they answer the question, "How much more would an elasticity estimate of -0.8 reduce CO_2 emissions as compared to an estimate of -0.7?" Using elasticity estimates from Spiller, Stephens, and Chen (2017) from table B1 in appendix B, the lowest possible elasticity estimates across each household characteristic (given the weighting system applied above) average at approximately -0.557. The highest possible elasticity estimates average at approximately -1.019. See table 2 below for calculations.

Using these values, it is possible to determine how much the quantity demanded of gasoline would decline due to an increase in price. From this decline, it is also possible to predict reductions in CO_2 emissions resulting from the gasoline price increase. Calculating reductions in CO_2 emissions requires using a derivation of the formula for the price elasticity of demand for gasoline:

$$\eta = \frac{\%\Delta Q_i}{\%\Delta P_i} = \frac{\Delta Q_d / Q_d}{\Delta P_i / P_i} \tag{1}$$

Where η = the price elasticity of demand for gasoline.

Q_d = quantity of gasoline demanded (gallons)

P_i = price of gasoline

Equation (1) can be rearranged to solve for ΔQ_d:

$$\Delta Q_d = \frac{\eta \Delta P_i * Q_d}{P_i} \tag{2}$$

Table 2. Weighted averages of lowest and highest price elasticity estimates

Variable	Lowest possible elasticity estimate		Highest possible elasticity estimate	
Household characteristic	η	Weights	η	Weights
Household size	-0.679	9.50%	-0.947	9.50%
Vehicles per household	-0.416	13.50%	-1.35	13.50%
Average MPG	-0.619	13.50%	-0.856	13.50%
Distance to MSA	-0.258	9.50%	-1.45	9.50%
Gasoline price	-0.425	13.50%	-0.989	13.50%
Average commute	-0.711	13.50%	-0.842	13.50%
Household income	-0.638	13.50%	-0.847	13.50%
Rural or urban?	-0.659	13.50%	-0.978	13.50%
Weighted averages	-0.55720	100.00%	-1.01909	100.00%

Note: Elasticities have been weighted according to their relative importance. All household characteristics have been equally weighted except for household size and distance to the nearest MSA, which have been given somewhat lower weights.

Importantly, all of the terms on the right-hand side of the equation are either known or can be estimated. The Georgetown Climate Center, for instance, estimated that the price of gasoline could increase anywhere from 5¢ to 17¢ throughout the TCI-P region depending on the cap level chosen. Given the price and quantity demanded of gasoline in 2017, the estimated ΔQ_d would therefore be

$$\Delta Q_d = \frac{\eta \Delta P_i * Q_d}{P_i} = \frac{(-0.557)(\$0.05) * 588{,}596{,}528\ gal}{\$2.39} = -6{,}858{,}750.337 \text{ gal.}$$

at a low-end price elasticity estimate. Remember that all elasticity estimates given so far are short-run estimates, and therefore the ΔQ_d given above should be interpreted only in terms of short-run changes in gasoline consumption (approximately 1 to 5 years). To calculate the total amount of CO_2 emissions reduced from gasoline, it is necessary to use the following formula:

$$\Delta Q_d * CO_2\ emissions\ per\ gallon = Total\ CO_2\ emissions\ reduced \quad (3)$$

The emissions factor (EF) for a gallon of E10 (10% ethanol, 90% gasoline) is approximately 0.008507 metric tons of CO_2 ($MTCO_2$). This emissions factor was calculated by multiplying the number of grams of carbon in a gallon of gasoline by 44/12 (the ratio of molecular weights between carbon and CO_2) and then dividing by the conversion factor for grams to metric tons (1,000,000 g/MT).[17] Therefore, total emissions would decline by approximately

$$6{,}858{,}750.337 * 0.008507 = 58{,}347.39 \text{ MTCO}_2$$

if the price of gasoline were to rise by 5¢ per gallon and the elasticity was -0.557. Using the same process outlined above, assuming a high-end household price elasticity estimate of -1.019, a 5¢ rise in the price of gasoline would lower GHG emissions by approximately 106,731 $MTCO_2$. Given a high-end price increase of 17¢ per gallon and a low-end elasticity estimate of -0.557, emissions would decline by approximately 198,358 $MTCO_2$. Given a high-end price increase of 17¢ per gallon and a high-end elasticity estimate of -1.019, emissions are expected to decline by approximately 362,884 $MTCO_2$.

According to consumption data from the MeDEP database and using an emissions factor of 0.008507, household emissions from E10 consumption in 2017 would have amounted to approximately 5,007,190.66 $MTCO_2$. Therefore, a low-end price increase of 5¢ per gallon and a low-end elasticity estimate of -0.557 would correspond to a

$$\frac{58{,}347.39\ MTCO_2}{5{,}007{,}190.66\ MTCO_2} * 100\% = 1.17\%$$

decline in CO2 emissions (the percent reduction in gallons of gasoline is identical for obvious reasons). Using the same process, a low-end price increase (5¢) and high-end

[17] According to the Transportation Energy Data Book from the Oak Ridge National Laboratory, a gallon of E10 contains approximately 2,347 grams of carbon (Davis and Boundy 2020).

Figure 5. Matrix of potential declines in $MTCO_2$

	Low-end elasticity (-0.557)	High-end elasticity (-1.019)
Low-end price increase (5 ¢)	-1.17% MTCO2	-2.13% MTCO2
High-end price increase (17 ¢)	-3.96% MTCO2	-7.25% MTCO2

elasticity estimate (-1.019) would correspond to a 2.13% decline in CO2 emissions. A high-end price increase (17¢) and low-end elasticity estimate (-0.557) would correspond to a 3.96% decline in emissions, and a high-end price increase (17¢) and high-end elasticity estimate (-1.019) would correspond to a 7.25% decline in emissions. Figure 5 shows this information in matrix form.

The preceding sensitivity analysis shows that household consumption of gasoline (expressed as a percent of total household gasoline consumption) will not change substantially in the short-term—no matter what the elasticity value may be—given a modest price increase of 5¢ per gallon. In fact, given this small change in price, low- and high-end elasticity estimates differ by less than a percentage point when it comes to their corresponding GHG emissions reductions. A high-end price increase would cause elasticity to matter somewhat more, with a difference of over three percentage points.

2.3 CO_2 Emission Reductions from the TCI-P

To calculate true emission reductions expected from the TCI-P, a similar process was followed. This time, however, the true elasticity estimate from section 2.1 was substituted for those in section 2.2. In other words, rather than using elasticity values of

-0.55720 or -1.01909, the adapted estimate representing Maine-specific demographics was used instead. Since the TCI-P entails a change in the price of gasoline, the elasticity estimate was adjusted upwards to reflect these changes. For example, the price of gasoline in 2017 was \$2.39 (AAA 2017). A 5¢ increase in the price of gasoline would cause the price of gasoline to rise to \$2.44 per gallon, creating a minor change in Maine households' price elasticity as well.

Gasoline consumption data from the MeDEP database was then used to determine how much gasoline consumption would fall given a 5¢, 9¢, or 17¢ increase in the price of gasoline. As mentioned above, the GCC's latest modeling results predicted a price increase of between 5¢ and 9¢ for a 26% decline in emissions over a period of 2022 to 2032. Results for a 17¢ per gallon price increase were considered in the present research as well, since a 17¢ rise was predicted in original modeling results. To determine emissions reductions from these respective price increases, changes in household consumption were then multiplied by an emissions factor of 0.008507 $MTCO_2$/gal.

2.4 Declines in State and Federal Tax Revenues

The current gasoline tax in Maine is 30¢ per gallon, plus an additional .01¢ fee.[18] The federal government also taxes the consumption of gasoline at a rate of 18.4¢ per gallon (Federal Highway Administration 2020). To calculate declines in state and federal tax revenues from the TCI-P, the changes in Maine households' consumption of gasoline given in section 2.3 were multiplied by state and federal tax rates.

[18] See 36 M.R.S. §2903(1) (2019) and 38 M.R.S. §551(4A-1) (2015) for the codified law on the 30¢ tax and .01¢ fee for gasoline, respectively.

2.5 Heterogeneous Effects of the TCI-P on Urban and Rural Households

Changes in the price and quantity of gasoline will inevitably impact Maine households. To measure the differential effects of the TCI-P on urban and rural Maine, the economic loss and burden were calculated for a 5¢, 9¢, and 17¢ increase in the price of gasoline, respectively. “Economic loss,” also known as “deadweight loss” and “welfare cost,” is defined as the cost associated with a reduction in market activity due to an increase in the price of gasoline, and it represents the share of the foregone consumer and producer surplus attributed to this reduction. Because consumers and producers gain value from buying and selling goods in the market, society is made worse off when this economic activity does not occur.

“Economic burden” also represents changes in consumer and producer surplus, however it is felt more directly than economic loss.[19] While consumers may not attempt to quantify how much worse off they are for not purchasing x gallons of gasoline, they can more easily observe a price increase of y. Specifically, economic burden represents the share of the reduction in consumer or producer surplus attributed to paying more (in the case of consumers) or receiving less (in the case of producers) for each unit of a good or service. Note that economic burden is not necessarily the same thing as an increase in total expenditures. If the price elasticity of demand for gasoline is sufficiently high, a price increase can cause the consumer to offset their quantity demanded enough to reduce total expenditures.

[19] Only the economic loss and burden faced by Maine households was calculated in the present analysis since, to the author’s knowledge, the price elasticity of supply for gasoline in Maine is not known.

2.5.1 Estimating Economic Loss

To calculate the portion of economic loss (foregone market activity) households face due to an increase in the price of gasoline, the change in quantity demanded of gasoline was multiplied by the various price changes of 5¢, 9¢, and 17¢.[20] For example, the (short-term) annual economic loss for urban Maine given a 5¢ change in the price of gasoline would be:

$$-3{,}721{,}075.62 * \$0.05 = -\$186{,}053.78$$

This process was repeated for all relevant quantity and price combinations for rural and urban Maine, for a total of six combinations.

For comparison, these numbers can be expressed as a percentage of households' current annual expenditures on fuel, fuel taxes, and driving costs. Doing so provides a better sense of the relative magnitude of these economic losses. I calculated fuel costs by multiplying the price of gasoline by the total number of gallons consumed in urban and rural Maine in 2017, given hypothetical price increases of 5¢, 9¢, or 17¢. Households' annual expenditures on fuel taxes in 2017 were calculated by multiplying total taxes and fees per gallon (federal and state) of E10 by the number of gallons consumed in urban and rural Maine, respectively.

Economic loss can also be expressed in terms of the annual costs of driving per household. To calculate driving costs, I adapted estimates from a 2019 American Automobile Association (AAA) brochure to reflect Maine's fuel prices and fuel economy

[20] The technique used to calculate the economic loss (multiplying the change in the quantity demanded of gasoline by the change in price) suggests that the estimate is an upper bound estimate, which is only appropriate for small, incremental changes in price, which is true in the case of the TCI-P. Because this is an upper bound estimate, the true value of economic loss faced by households is not likely to be this high.

(American Automobile Association 2019).[21] The brochure estimated average driving costs for 9 categories of vehicles, including: (1) small sedans, (2) medium sedans, (3) large sedans, (4) small sports utility vehicles (SUVs), (5) medium SUVs, (6) minivans, (7) pickup trucks, (8) hybrid cars, and (9) electric cars, weighting each by their national sales to generate a fleet-wide average driving cost estimate (American Automobile Association 2019). The costs of driving were split into two categories: operating costs (variable costs) and ownership costs (fixed costs). Variable costs, such as fuel, maintenance, and repairs (American Automobile Association 2019), are prominent in consumers' minds and are therefore more likely to have an effect on households' consumption decisions. Fixed costs, such as full-coverage insurance, vehicle depreciation, license and registration, taxes, and finance charges (American Automobile Association 2019), are less prominent in consumers' minds since they tend to change infrequently or be intangible. For example, vehicle depreciation is not prominent and is more difficult to conceptualize than variable costs such as the price of gasoline. For the purposes of this analysis, the variable, fixed, and total costs have been separated.

Since the average vehicle in Maine is 11.2 years old (Auto Alliance n.d.), most households do not face depreciation or finance costs. Therefore, the costs of driving used vehicles, which do not face depreciation and finance costs, were also estimated. Ideally, sales tax would also be subtracted from the ownership costs of used vehicles, but AAA combined taxes with license and registration fees, making it impossible to isolate the

[21] For simplicity, I have assumed the costs of driving are the same for rural and urban households in Maine. In reality, driving costs for rural households are likely higher since these households drive greater distances and consume more gasoline per year. However, adapting my estimate to reflect this fact would generate a difference in variable costs of less than $50 per year between rural and urban households, which would have virtually no effect on my analysis of households' economic loss and burden.

dollar value used. It is likely that my adapted driving cost estimates for used vehicles are therefore on the high end, especially since AAA assumed a full-coverage car insurance policy.

Since the costs of driving vary depending on how far a vehicle drives, a range of driving costs were estimated for vehicles that travel anywhere from 10,000 to 15,000 miles per year. The average Mainer drives approximately 13,500 miles per year (Maine Department of Transportation 2015), which figures to approximately 11,363 miles per vehicle per year.[22] Therefore, the driving costs of vehicles that travel 11,363 miles per year were also estimated. Variable, fixed, and total costs for both used and new vehicles were calculated and then multiplied by the number of vehicles per household, given in section 2.1 to be 2.06, to estimate household driving costs in Maine.

Since the costs of driving depend in part on the price of gasoline, fuel prices were adjusted upwards by 5¢, 9¢, and 17¢ per gallon. The average Maine fuel economy of 21.76 MPG in 2017 was incorporated in calculations for the costs of driving used vehicles, while AAA's implied fuel economy of 23.09 MPG was incorporated in calculations for the costs of driving new vehicles (American Automobile Association 2019). To match AAA's own calculations, a sum of $326 was deducted from depreciation costs for new vehicles that travel under 15,000 miles per year.

To express economic loss as a percent of the costs of driving, the economic losses faced by households were divided by the variable, fixed, and total costs of driving for all

[22] The average licensed driver travels 13,500 miles per year (Maine Department of Transportation 2015). Since there are approximately 1.73 licensed drivers per household (Bureau of Motor Vehicles 2017a; (United States Census Bureau n.d.), this equates to roughly 23,407 miles per household per year. There are 2.06 vehicles per household (Bureau of Motor Vehicles 2017b; United States Census Bureau n.d.), for an average of roughly 11,363 miles per vehicle per year.

four VMT scenarios. For example, for a 5¢ increase in the price of gasoline, the economic loss faced by urban households was estimated to be \$0.82. Expressed as a percent, this is less than 0.02% of a household's variable driving costs of a used vehicle given an annual VMT of 10,000 miles per vehicle (see table E1 in appendix E):

$$\frac{\$0.82}{\left[\left(\frac{\$2.44}{21.76}\right) + \$0.0894\right] \times 10{,}000 \times 2.06} \times 100\% \approx .02\%$$

Where \$0.82 = economic loss faced by urban households given a 5¢ increase in price

\$2.44 = price of gasoline after a 5¢ increase in price

21.76 = average fuel economy in Maine

\$0.0894 = other variable costs per mile other than fuel[23]

2.06 = number of vehicles per household

This same process was followed for variable costs for new vehicles, fixed costs for used vehicles, fixed costs for new vehicles, and total costs for new and used vehicles for each price increase and VMT combination.

2.5.2 Estimating Economic Burden

Households' economic burden was estimated by multiplying the "after-tax" (post-TCI-P) quantity demanded of gasoline by the amount of the price increase for all relevant combinations of price, elasticity, and quantities demanded in urban and rural Maine. The after-tax quantity demanded of gasoline was calculated by adding the change in quantities

[23] Other variable costs include maintenance, tires, and repairs (American Automobile Association 2019).

for each potential price increase (5¢, 9¢, and 17¢) to the original quantities demanded for urban and rural Maine.

Fuel costs and fuel taxes were calculated in the same manner as for the previous subsection on economic loss. The economic burden from various TCI-P caps was also expressed in terms of the annual costs of driving. As before, data from a 2019 AAA brochure was used to create adapted estimates of the variable, fixed, and total costs for new and used vehicles for each possible price increase and VMT combination. Maine-specific gasoline prices and household fuel economy (except in the case of new vehicles, for which I used AAA's implied fuel economy of 23.09 MPG) were used to better reflect the costs of driving in Maine (American Automobile Association 2019).

2.6 The Driving Costs of Various Vehicle Types

Since not all households own the same vehicle types, it was necessary to express the economic loss and burden of the TCI-P as a percent of the driving costs of various vehicle categories. These categories were listed in AAA's 2019 brochure as small, medium, and large sedans; small and medium SUVs; minivans; pickup trucks; hybrid cars; and electric cars.[24] Before making these calculations, variable costs were adjusted to reflect Maine gasoline prices. This required calculating the implied fuel economy for each vehicle type. For example, AAA estimated the fuel cost in 2019 to be 8.36¢ per mile for small sedans (American Automobile Association 2019). At a gasoline price of $2.679

[24] Each category contains the weighted average costs of five top selling makes and models of 2019. Hybrid cars are assumed to be full hybrids rather than plug-in hybrids, since each of AAA (2019)'s five models have hybrid versions, including the Toyota RAV4 (Trotter 2020a), the Hyundai Ioniq (Trotter 2020b), the Kia Niro (Koses 2020a), the Ford Fusion (Koses 2020b), and the Toyota Prius Liftback (Koses 2020c). If they were not full hybrids, but rather plug-in hybrids, calculating economic loss and burden as a percent of the costs of driving would require splitting the cost of fuel into its component parts, gasoline and electricity, and determining how many vehicle miles ought to be attributed to each. This is a complicated process for which data is lacking.

per gallon, this means AAA's implied fuel economy for new model small sedans in 2019 is:

$$\frac{\$2.679}{\$0.0836} \approx 32.05\ MPG.$$

Therefore, at a price of \$2.39. the fuel cost per mile for small sedans in Maine would be:

$$\frac{\$2.39}{32.05\ MPG} = \$0.0746.$$

This process was replicated for all vehicle categories except electric vehicles, which do not run on gasoline. Fuel costs per mile were then added to maintenance and other variable costs per mile before being multiplied by total VMT per year. In order to provide a better understanding of how the costs of driving vary across households, I used four different VMT estimates, including 10,000, 12,500, 15,000, and the Maine average estimate of 11,363 per vehicle. Products were then added to fixed costs per year for each respective vehicle category. Finally, annual costs per vehicle were multiplied by the number of vehicles per household to estimate the costs of driving per household given the ownership of each vehicle type. For simplicity, I calculated the costs of driving given only a 9¢ increase in the price of gasoline.

In order to express these costs as percentages, I also calculated the economic loss and burden for the average Maine household.[25] This required using an estimate for the statewide price elasticity of demand for gasoline. The elasticity was calculated using the same method given in section 2.1, assuming a 9¢ increase in the price of gasoline.

[25] In this case, I opted not to express percentages for rural and urban Maine separately. The point of this analysis was to assess how households with different vehicles would be affected by the TCI-P rather than households from different parts of the state.

CHAPTER III

RESULTS

3. Short-run Elasticities

Short-run elasticity estimates for the state of Maine and its rural and urban areas are shown in tables 3, 4, and 5. Individualized estimates for each of the 8 household characteristics are given, including: (1) household size, (2) vehicles per household, (3) average fuel economy (MPG), (4) distance to the nearest MSA, (5) gasoline price, (6), average commute, (7) household income, and (8) whether or not the household is rural or urban (or both in the case of the statewide elasticity estimate).

Note that elasticity estimates have been weighted according to their relative importance. The variables "vehicles per household," "average MPG," "gasoline price," "average commute," "household income," and "rural versus urban" all received equal weights of 13.5%, while "household size" and "distance to MSA" received slightly lower weights of 9.5%. The characteristics "household size" and "distance to MSA" were assumed to be less important than other household characteristics in predicting Maine household's sensitivity to changes in the price of gasoline. For example, it is likely that household income is more important in determining the amount of gasoline consumed than household size or distance to the nearest MSA. The weighted average elasticities for

Table 3. Weighted Maine average price elasticity calculations by household characteristic

Maine Average Elasticity Estimate			
Category	Maine Average	Weights	η
Household size	2.33	9.50%	-0.77030
Vehicles per household	2.06	13.50%	-0.84710
Average MPG	21.76	13.50%	-0.89745
Distance to MSA	59.99 km	9.50%	-1.61901
Gasoline price	2.39	13.50%	-0.60031
Average commute	24 min.	13.50%	-0.87400
Household income	$55,425	13.50%	-0.72557
Rural or urban?	Both	13.50%	-0.84622
Weighted average		100.00%	-0.87372

Table 4. Weighted urban price elasticity calculations by household characteristic

Maine Urban Elasticity Estimate			
Category	Urban average	Weights	η
Household size	2.35	9.50%	-0.77250
Vehicles per household	2.06	13.50%	-0.84710
Average MPG	21.76	13.50%	-0.89745
Distance to MSA	30.16 km	9.50%	-0.50500
Gasoline price	$2.39	13.50%	-0.60031
Average commute	22.96 min.	13.50%	-0.86568
Household income	$60,571.24	13.50%	-0.76716
Rural or urban?	Urban	13.50%	-0.65900
Weighted average		100.00%	-0.74732

Table 5. Weighted rural price elasticity calculations by household characteristic

Maine Rural Elasticity Estimate			
Category	Rural Average	Weights	η
Household size	2.32	9.50%	-0.76920
Vehicles per household	2.06	13.50%	-0.84710
Average MPG	21.76	13.50%	-0.89745
Distance to MSA	80.97 km	9.50%	-2.50770
Gasoline price	$2.39	13.50%	-0.60031
Average commute	24.73 min.	13.50%	-0.87984
Household income	$53,700.96	13.50%	-0.71109
Rural or urban?	Rural	13.50%	-0.97800
Weighted average		100.00%	-0.97467

Maine, urban Maine, and rural Maine are therefore estimated to be -0.874, -0.747, and -0.975, respectively. These results are consistent with Spiller, Stephens, and Chen (2017), who estimated that rural households are in general more price elastic than urban households, though Wadud, Graham, and Noland (2010) found the opposite result.

3.1 Expected Short-term CO_2 Emission Reductions

In the previous section, it was estimated that Maine households' short-term price elasticity estimate is approximately -0.874. In 2017, households consumed approximately 589 million gallons of gasoline at a price of $2.39 per gallon, according to the Maine DEP database and AAA gasoline price index, respectively. Given a price increase of 5¢ per gallon, Maine's elasticity estimate would rise to -0.876 (because households become more sensitive as prices rise), and households would be expected to reduce their quantity demanded of gasoline by

$$\Delta Q_d = \frac{\eta \Delta P_i * Q_d}{P_i} = \frac{(-0.876)(\$0.05) * 588{,}596{,}528\ gal}{\$2.39} = -10{,}786{,}832 \text{ gal.}$$

which equates to approximately 91,764 $MTCO_2$ using an emissions factor of 0.008507 $MTCO_2$/gal. Given a price increase of 9¢ per gallon, elasticity would climb to roughly -0.878, gasoline consumption would fall by 19,460,627 gallons, and CO_2 emissions would be reduced by 165,552 $MTCO_2$.[26] Given a price increase of 17¢ per gallon, elasticity would climb to -0.882, gasoline consumption would fall by 36,926,428 gallons, and CO_2 emissions would be reduced by 314,133 $MTCO_2$. These reductions correspond to roughly 1.8%, 3.3%, and 6.3% of Maine household vehicles' $MTCO_2$ emissions from gasoline in 2017, respectively. In other words, it is reasonable to expect the TCI-P would precipitate a reduction in Maine household vehicles' CO_2 emissions of anywhere from 1.8% to 6.3% given a minimum increase of 5¢ per gallon and a maximum of 17¢ per gallon.[27] Note that due to the proportional relationship between emissions and gallons of gasoline, these percentages also correspond to decreases in the consumption of E10.

According to the MeDEP database (mentioned above), the transportation sector consumed approximately 649,785,827 gallons of gasoline in 2017, while households consumed approximately 588,596,528 gallons. From this difference, it is possible to express the reduction in household consumption of gasoline as a percent of economy-

[26] The Eastern Research Group estimated that a 10¢ rise in state fuel taxes would result in an economy-wide reduction (including diesel and gasoline consumption) of 127,500 $MTCO_2$ (Eastern Research Group [ERG] 2020). This result could arise if the ERG used a lower price elasticity of demand for motor fuel in its model. See the results of the sensitivity analysis below for more information.

[27] These calculations exclude household consumption of diesel fuel. Under different circumstances (e.g., if I were analyzing elasticities in England), excluding diesel from the analysis could provide misleading results, since households do indeed own and operate vehicles that run on diesel fuel, and since diesel fuel is regulated under the TCI-P. However, as stated previously, households' consumption of diesel fuel is relatively small. Maine household vehicles combusted approximately 10,491,038 gallons of diesel fuel in 2017 compared to 588,596,528 gallons of E10, according to the MeDEP database mentioned above. Diesel therefore accounts for a very small percentage (roughly 1.75Maine %) of household's overall consumption of motor fuel. Thus, it is not likely that price increases for diesel—which has its own price elasticity apart from gasoline—would much change the totals given above. Furthermore, it is beyond the scope of the present research to estimate Maine households' price elasticity of demand for diesel fuel. I might restate, however, that the estimate for Maine households' price elasticity of demand for gasoline does incorporate diesel vehicles through the fuel economy characteristic, a limitation I discuss below.

wide consumption. Given a 5¢ increase in the price of gasoline, a 10,786,832-gallon reduction in household consumption corresponds to approximately 1.7% of state-wide consumption. Similarly, a 9¢ price increase and a reduction of 19,460,627 gallons of gasoline corresponds to approximately 3% of state-wide consumption, and a 17¢ price increase and a household reduction of 36,926,428 gallons of gasoline corresponds to approximately 5.7% of state-wide consumption.

A sensitivity analysis was conducted using elasticities 50% lower and 50% higher than the elasticity of -0.878 given above for a 9¢ change in price. This corresponds to respective elasticities of -0.439 and -1.317. Using an elasticity of -0.439 and a price increase of 5¢, the analysis found that households would reduce their quantity demanded of gasoline by -5,405,730 gallons, or approximately 0.9% of total household consumption of gasoline. Using the same elasticity and a price increase of 9¢, the analysis found that households would reduce their consumption of gasoline by -9,730,313 gallons, or approximately 1.7% of total household consumption of gasoline. For a 17¢ increase in price and a 50% lower elasticity, the sensitivity analysis found that households would reduce their fuel consumption by 18,379,481 gallons, or 3.1% of total household consumption of gasoline. These values correspond to reductions of 45,987 $MTCO_2$, 82,776 $MTCO_2$, and 156,354 $MTCO_2$, respectively.

Given an elasticity estimate 50% higher than -0.878, a 5¢ increase in the price of gasoline would correspond to a reduction of 16,217,189 gallons of gasoline, or 2.8% of total household consumption. A 9¢ price increase would correspond to a reduction of 29,190,940 gallons and approximately 5.0% of total household consumption of gasoline, and a 17¢ price increase would correspond to a reduction of 55,138,442 gallons and approximately 9.4% of total annual household consumption of gasoline. These values correspond to reductions of 137,960 $MTCO_2$, 248,327 $MTCO_2$, and 469,062 $MTCO_2$, respectively.

3.2 Revenue Reductions

When households consume less gasoline in a given year, this has implications for state and federal tax revenues. The state of Maine currently charges an approximate 30.01¢ per gallon excise tax for gasoline, and the federal government levies an additional tax of 18.4¢ per gallon. Given the reductions mentioned above, a 5¢ increase in the price of gasoline is estimated to decrease state tax revenues from gasoline by over \$3.24 million:

$$-10{,}786{,}831.77\ gal * \$0.3001 = \$3{,}237{,}128.21$$

Using the same process, a 9¢ or 17¢ increase in the price of gasoline would lead to a decline in state revenue of approximately \$5.84 million or \$11.08 million, respectively. In 2017, the state of Maine took in approximately \$202.00 million in gasoline tax revenue (deLutio 2019). Therefore, a tax of 17¢ per gallon and a loss of \$11.08 million dollars corresponds to just 5.5% of total state revenues from gasoline taxes. When compared to total operating revenues for the state of Maine in 2017 (\$7.5 billion), this decline represents just 0.2% of the total (deLutio 2019).

Given a federal tax of 18.4¢ per gallon, a 5¢ increase in the price of gasoline would lead to an approximate \$1.98 million loss in federal revenue. Similarly, a 9¢ increase would lead to an approximate \$3.58 million loss, and a 17¢ increase would lead to an approximate \$6.79 million decline in federal revenue. In total, taking both state and federal losses into account, price increases of anywhere from 5¢ to 17¢ on the gallon could result in \$5.22 million to \$17.88 million declines in revenue from Maine households annually.[28]

A sensitivity analysis was conducted using elasticities 50% lower and 50% higher than the elasticity of -0.878 given above for a 9¢ change in price. This analysis produced different declines in households' quantities demanded of gasoline and therefore declines in state and federal tax revenues. Given a 5¢ change in price and an elasticity of -0.439, the analysis found potential state and federal tax revenue losses of approximately \$1.62 million and \$995,000, respectively. For a 9¢ change in price, the analysis found respective state and federal tax revenue losses of \$2.92 million and \$1.79 million, and for a 17¢ change in price, \$5.52 million and \$3.38 million.

Given an elasticity estimate 50% higher than -0.878, a 5¢ price increase was estimated to result in a revenue reduction of approximately \$4.87 million at the state level and \$2.98 million at the federal level. Similarly, a 9¢ price increase was estimated to result in a revenue reduction of \$8.76 million at the state level and \$5.37 million at the federal level. Finally, a 17¢ price increase was estimated to result in revenue losses of \$16.55 million at the state level and \$10.15 million at the federal level.

3.3 Heterogeneous Effects

The economic losses and burdens of the TCI-P were calculated assuming price increases of 5¢, 9¢, or 17¢. As mentioned in section 3.2, consumers are expected to

[28] It is worth reiterating that these values correspond to declines in the tax revenue from households only. In reality, changes in the price of gasoline and diesel will prompt a decline in consumption for the entire Maine economy, resulting in greater revenue losses.

Table 6. Summary of reductions in gasoline consumption for urban Maine

Urban Maine		
Δ Price (gasoline)	Elasticity	Δ Consumption (gallons of E10)
$0.05	-0.74973	-3721075.62
$0.09	-0.75166	-6715178.35
$0.17	-0.75553	-12749531.83

Table 7. Summary of reductions in gasoline consumption for rural Maine

Rural Maine		
Δ Price (gasoline)	Elasticity	Δ Consumption (gallons of E10)
$0.05	-0.97708	-7182040.19
$0.09	-0.97901	-12953208.02
$0.17	-0.98288	-24563888.77

become more sensitive to price as prices rise (Spiller, Stephens, and Chen 2017). At a price of $2.44, the elasticity for urban Maine households was estimated to be -0.750. At a price of $2.48, it was estimated to be -0.752, and at a price of $2.56, it was estimated to be -0.756. At a price of $2.44, the elasticity for rural Maine was estimated to be -0.977. At a price of $2.48, it was estimated to be -0.979, and at a price of $2.56, it was estimated to be -0.983. Maine households consumed 588,596,528 gallons of E10 in 2017, with urban Maine consuming 237,241,960 gallons and rural Maine consuming 351,354,568.[29] Given these values, a 5¢ increase in the price of gasoline was estimated to reduce urban consumption by 3,721,076 gallons, a 9¢ increase by 6,715,178 gallons, and a 17¢ increase by 12,749,532 gallons. A 5¢ increase in the price of gasoline was estimated to reduce rural consumption by 7,182,040 gallons of gasoline, a 9¢ increase by 12,953,208, gallons, and a 17¢ increase by 24,563,889 gallons. Results for urban and rural Maine are summarized in tables 6 and 7, respectively.

[29] Data came from the MeDEP database mentioned above.

3.3.1 Economic Loss

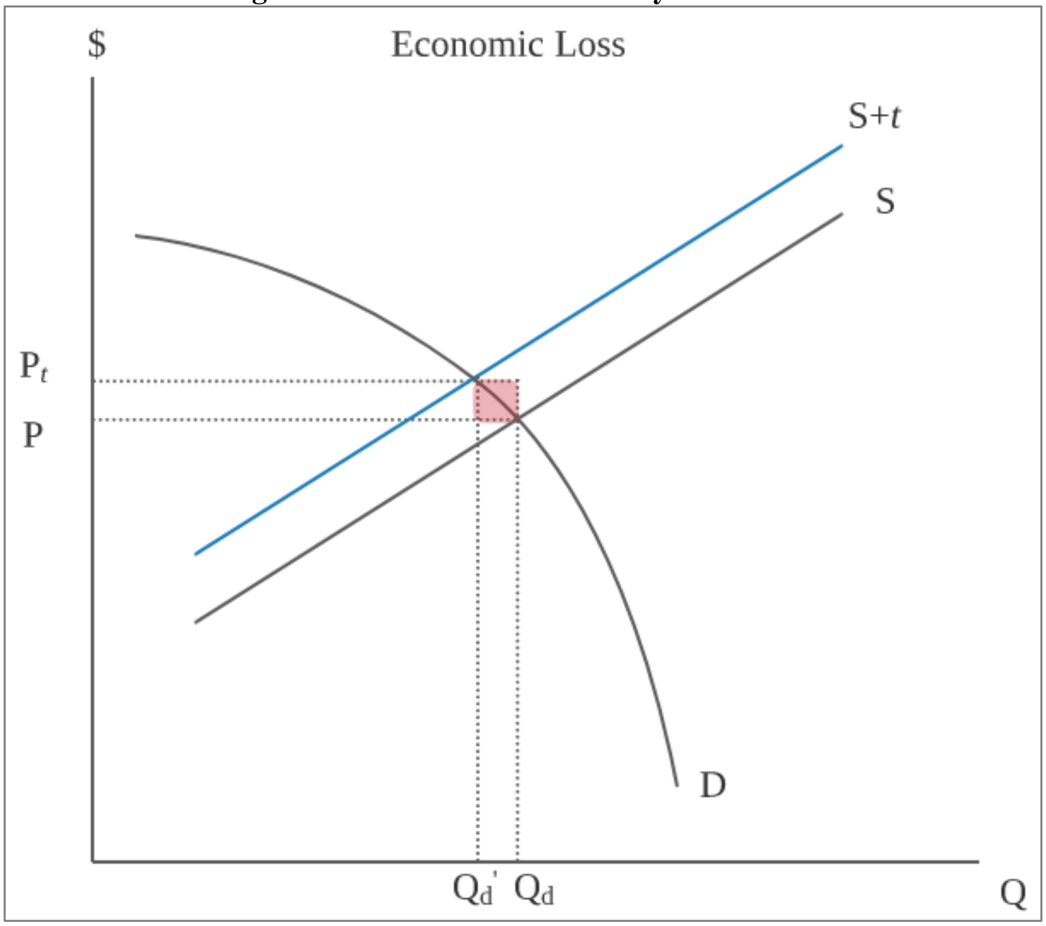
Figure 6 shows the economic loss society would face because of reductions in household consumption of gasoline. The red-shaded region represents the upper bound of this loss. Note that this is an illustrative graph and is not meant to represent the true area of households' economic loss.

Urban households were estimated to bear (short-term) annual economic losses ranging from approximately $186,054 to over $2.17 million assuming price increases of 5¢ to 17¢. Rural households were estimated to bear (short-term) annual economic losses ranging from approximately $359,102 to over $4.18 million depending on the price increase, for a total of roughly $545,156 to $6.35 million for all households statewide. See tables 8 and 9 below for a summary of the economic losses from rural and urban households' reduced consumption of gasoline.

According to the Maine DEP database, at a price of $2.39, Mainers in urban counties consumed approximately $567,008,285 worth of gasoline, while Mainers in rural counties consumed approximately $839,737,417 worth. After a price increase to $2.44 per gallon (a 5¢ increase), fuel costs would rise to $569,790,958 and $839,780,967 for urban and rural Maine, respectively.[30] Given a 9¢ increase, fuel costs would rise to $571,706,419 for urban Maine but fall to $839,235,372 in rural Maine due to greater price sensitivity. Given a 17¢ increase, fuel costs would rise to $574,700,616 for urban Maine but fall even further to $836,584,138 in rural Maine. There are a couple possible reasons why rural Mainers spent more on fuel than urban Mainers in 2017. For one, all

[30] Changes in fuel costs arise from changes in the elasticity estimate (and therefore changes in the quantity of gasoline demanded) and rising gasoline prices.

Figure 6. Economic loss faced by consumers



Note: Figure 6 shows the upper bound of economic loss faced by consumers from an increase in the price of gasoline. The TCI-P would force fuel suppliers to buy allowances in proportion to the amount of fuel they sell. This shifts the supply curve up and to the left as suppliers try to pass costs onto consumers. The quantity demanded of gasoline falls from Q_d to Q_d', and the price of gasoline rises from P to P_t. The resulting economic loss is shown by the red shaded region. According to Spiller, Stephens, and Chen (2017), for small, incremental changes in price (around 10% or less), economic loss can be measured by multiplying the change in the quantity of gasoline demanded by the change in price, as shown above. This estimate is considered an upper bound because it exceeds true economic loss by the triangular region above the demand curve. The importance of the upper bound estimate has to do with the shape of the demand curve. When the demand curve is concave to the origin, as depicted above, it is bowed outward and therefore true economic loss will be larger than it would be if the demand curve were convex or linear. This is captured in the upper bound estimate. The demand curve may be concave to the origin in the event that consumers become more sensitive to price as the price of gasoline rises (i.e., elasticity rises with price). Spiller, Stephens, and Chen (2017) found this to be the case.

Table 8. Economic loss per urban household

Urban Maine				
Δprice (gasoline)	Annual economic loss	Annual economic loss per household	Loss as a percent of fuel costs	Loss as a percent of fuel taxes
$0.05	-$186,054	-$1	0.0%	-0.2%
$0.09	-$604,366	-$3	-0.1%	-0.5%
$0.17	-$2,167,420	-$10	-0.4%	-2.0%

Table 9. Economic loss per rural household

Rural Maine				
Δprice (gasoline)	Annual economic loss	Annual economic loss per household	Loss as a percent of fuel costs	Loss as a percent of fuel taxes
$0.05	-$359,102	-$1	0.0%	-0.2%
$0.09	-$1,165,789	-$4	-0.1%	-0.7%
$0.17	-$4,175,861	-$13	-0.5%	-2.6%

but three counties in Maine were considered rural in the present analysis, which meant more households were considered rural than urban. In addition, rural households consume more gallons of gasoline on average than do urban households,[31] probably due to their longer commutes and greater distance from MSAs. As a percent of fuel expenditures, urban Mainers faced less economic loss on average than rural Mainers, although the loss for both regions was less than one half of 1% of fuel expenditures.

Total taxes and fees in Maine amount to 48.41 cents per gallon, for a total tax burden of $114,848,833 for urban Maine and $170,090,746 for rural Maine given a price of $2.39 per gallon of gasoline. Given a 5¢ increase in the price of gasoline, the tax burden was estimated to fall by $113,047,460 in urban Maine and by $166,613,921 in rural Maine.[32] Assuming a 9¢ increase in the price of gasoline, the tax burden was

[31] In 2017, rural households were estimated to consume approximately 1,064 gallons of gasoline on average. In the same year, urban households were estimated to consume approximately 1,046 gallons of gasoline. These numbers were calculated by dividing the quantity of E10 consumed in rural and urban Maine by the number of households in each region. Consumption data came from the MeDEP database, and the number of households in rural and urban Maine was taken from the American Community Survey's 5 year estimates (United States Census Bureau n.d.).
[32] Changes in the tax burden arise from consumers' reduced quantity demanded of gasoline and rising elasticities.

estimated to fall by $111,598,015 in urban Maine and $163,820,098 in rural Maine. Given a 17¢ increase, the tax burden was estimated to fall by $108,676,785 in urban Maine and by $158,199,368 in rural Maine. As a percent of fuel tax expenditures, rural households were again found to face more of the economic loss from increases in the price of gasoline than were urban households. On average, rural households faced an economic loss as a percent of fuel taxes ranging from .2% to 2.6% depending on the price increase, and urban households faced an economic loss as a percent of fuel taxes ranging from .2% to 2.0% depending on the price increase. These results are presented in full in tables 8 and 9 above.

Variable costs for a used vehicle, variable costs for a new vehicle (excluding depreciation and finance costs), fixed costs for a used vehicle, and fixed costs for a new vehicle are shown in the first four rows of table 10. The penultimate and final rows show total annual driving costs for new vehicles and the average Maine vehicle, respectively. The average Maine vehicle is 11.2 years old and therefore does not face depreciation or finance costs, as explained above. Table 11 shows the same cost scenarios for the average Maine household (as opposed to costs for a single vehicle).

It is important to note that the values in tables 10 and 11 reflect a price of $2.39 per gallon of gasoline. If the TCI-P is implemented in Maine, household driving costs would be somewhat higher. Results are presented in tables E1 through E6 in appendix E. Since the economic loss faced by rural households was higher for each price increase, and since I held driving costs constant across rural and urban households, rural households were regularly shown to face higher economic losses as a percent of driving costs than urban households, with disparities rising the greater the increase in the price of

Table 10. Annual driving costs per vehicle

Annual driving costs per vehicle (statewide average)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Variable (used)	$1,992.35	$2,490.43	$2,988.52	$2,263.82
Variable (new)	$1,928.86	$2,411.08	$2,893.30	$2,191.69
Fixed (used)	$1,947.00	$1,947.00	$1,947.00	$1,947.00
Fixed (new)	$5,875.00	$5,875.00	$6,201.00	$5,875.00
Total for new vehicles	$7,803.86	$8,286.08	$9,094.30	$8,066.69
Total for average Maine vehicles	$3,939.35	$4,437.43	$4,935.52	$4,210.82

Table 11. Annual household driving costs

Annual household driving costs (statewide average)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Variable (used)	$4,104.23	$5,130.29	$6,156.35	$4,663.47
Variable (new)	$3,973.46	$4,966.82	$5,960.19	$4,514.88
Fixed (used)	$4,010.82	$4,010.82	$4,010.82	$4,010.82
Fixed (new)	$12,102.50	$12,102.50	$12,774.06	$12,102.50
Total for new vehicles	$16,075.96	$17,069.32	$18,734.25	$16,617.38
Total for average Maine vehicles	$8,115.05	$9,141.11	$10,167.17	$8,674.29

gasoline. However, the economic losses of urban and rural households never exceeded 0.3% of total driving costs for the average Maine vehicle—regardless of the price increase or VMT.

3.3.2 Economic Burden

While the economic loss provides a sense of the cost to households from foregone market activity, the economic burden provides a more direct assessment of the differential burden households in rural and urban Maine might face given TCI-P membership. The economic burden faced by consumers is illustrated in figure 7 below.

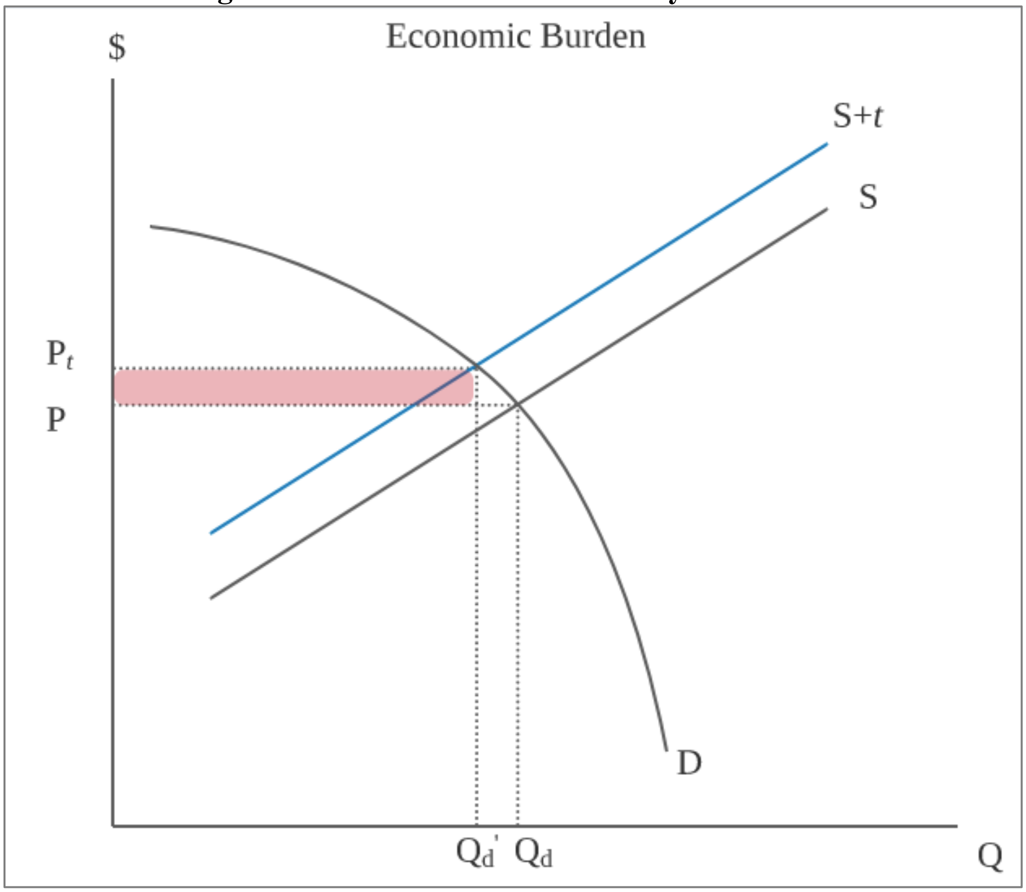
Households in urban Maine were estimated to reduce their quantity demanded by approximately -3,721,076 gallons, such that the after-tax quantity demanded would fall to

$$237{,}241{,}960\ gal. + (-3{,}721{,}076\ gal.) = 233{,}520{,}884\ gal.$$

given a 5¢ change in price. Tables 12 and 13 below show how price elasticities and gallons of gasoline demanded by rural and urban Maine change as prices rise.

The economic burden faced by households in urban Maine ranged from approximately $11.68 million to roughly $38.16 million depending on the carbon cap. In

Figure 7. Economic burden faced by consumers



Note: Figure 7 shows the economic burden faced by consumers created by the TCI-P. The red shaded region between Q_d' and the origin represents the share of total costs consumers would pay for gasoline on an annual basis due to a price increase in the amount of P_t – P. Due to the difference of elasticities in rural and urban Maine, each household will face a different economic burden. Ceteris paribus, the more elastic the demand curve, the lower the economic burden of the cap-and-invest system. However, aside from differences in elasticities, rural and urban households in Maine also differ in terms of income and quantity of gasoline demanded. These differences will create substantial variability in the true burden households face from the TCI-P.

rural Maine, households' economic burden ranged from approximately $17.21 million to $55.55 million depending on the cap level selected and the associated price increases. Economic burdens for urban and rural Maine are given in tables 14 and 15, respectively.

Table 12. After-tax quantity demanded of gasoline (urban Maine)

Urban		
Δ Price	Elasticity	After-tax Q-demanded (gallons)
$0.05	-0.74973	233,520,884
$0.09	-0.75166	230,526,782
$0.17	-0.75553	224,492,428

Table 13. After-tax quantity demanded of gasoline (rural Maine)

Rural		
Δ Price	Elasticity	After-tax Q-demanded (gallons)
$0.05	-0.97708	344,172,527
$0.09	-0.97901	338,401,360
$0.17	-0.98288	326,790,679

Table 14. Economic burden per urban household

Urban Maine				
Δprice (gasoline)	Annual economic burden	Annual burden per household	Burden as a percent of fuel costs	Burden as a percent of fuel taxes
$0.05	$11,676,044	$51	2.0%	10.3%
$0.09	$20,747,410	$91	3.6%	18.6%
$0.17	$38,163,713	$168	6.6%	35.1%

Table 15. Economic burden per rural household

Rural Maine				
Δprice (gasoline)	Annual economic burden	Annual burden per household	Burden as a percent of fuel costs	Burden as a percent of fuel taxes
$0.05	$17,208,626	$52	2.0%	10.3%
$0.09	$30,456,122	$92	3.6%	18.6%
$0.17	$55,554,415	$168	6.6%	35.1%

Since the population size varies between rural and urban Maine, I also report the burden per household in both regions.[33] For example, at a price of $2.44 per gallon (5¢ above 2017 prices), households in urban Maine were estimated to face an economic burden of

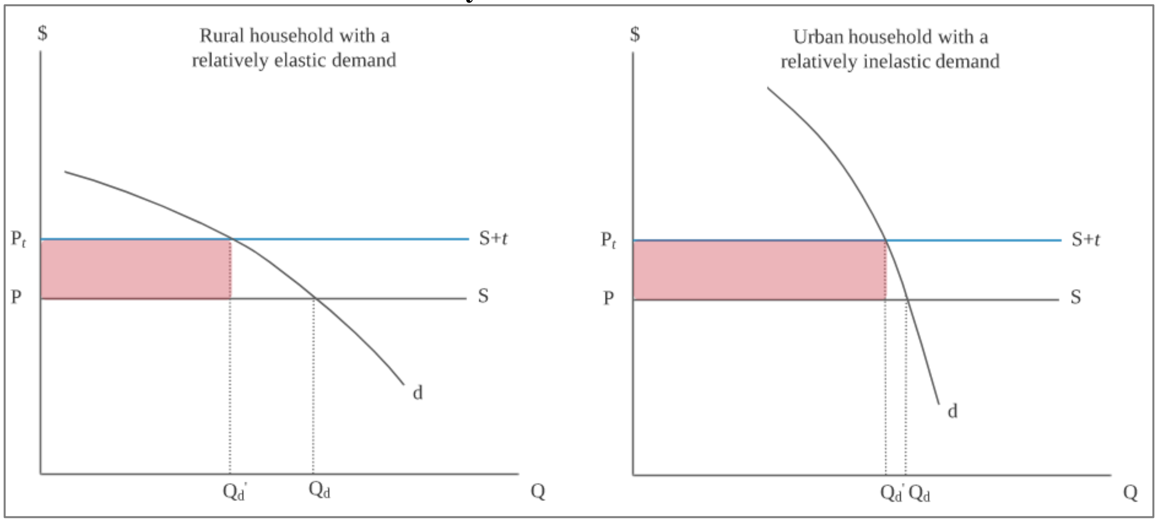
[33] A different method of calculation produces similar values for the economic burden per household. For example, dividing the annual VMT per licensed driver (13,500) by the average fuel economy in the state (21.76 MPG) and multiplying by the number of licensed drivers per household (1.73) produces a figure of approximately 1073.3 gallons of gasoline per household per year. Multiplying this number by $0.05 per gallon would mean the average household in Maine would face an economic burden of approximately $53.8 per year, only slightly higher than the figure shown above. However, estimating the economic burden in this way does not account for the fact that households reduce their consumption of gasoline as prices rise. If it did, this would lower the economic burden estimate somewhat. Additionally, not all Mainers drive 13,500 miles per year on gasoline—some drive on diesel fuel, which was excluded from analysis for obvious reasons. This lower VMT estimate would also reduce the economic burden estimate.

approximately $51. Several factors are at play in determining households' economic burdens. These include the price elasticity of demand, the quantity demanded of a good, and household income (Spiller, Stephens, and Chen 2017). *Ceteris paribus*, a demand curve that is relatively elastic will absorb less of the economic burden of a price increase. For example, figure 8 shows two household demand curves with relatively elastic and inelastic demand on the left- and right-hand sides, respectively. For the same initial quantity demanded, income levels, and change in price, the household with relatively elastic demand is shown to bear a lower economic burden—illustrated by the different sizes of the red shaded regions for each household.

However, if the initial quantities demanded vary between households, it is still possible for the rural household to experience a greater economic burden given the same increase in price. In 2017, urban households in Maine consumed an average of 1,046 gallons of gasoline per household, while rural households consumed an average of 1,064 gallons per household (a difference of about 1.7%).[34] As shown in tables 10 and 11 above, this difference was sufficient to offset the differential effect of varying elasticities on individual households' economic burden for price changes of 5¢ and 9¢. In other words, even though rural Maine households have relatively higher elasticities, on average they consume more gallons of gasoline such that their nominal economic burdens are higher than for urban households. Figure 9 presents a visual illustration of this

[34] According to the MeDEP database, households in rural counties consumed more gallons of gasoline than households in urban counties in 2017. To calculate the difference in consumption between households, I divided total gallons of gasoline by the number of households in rural and urban counties using data from the American Community Survey estimates for 2014-18 (United States Census Bureau n.d.).

Figure 8. Differential economic burden for households with relatively elastic and inelastic demand

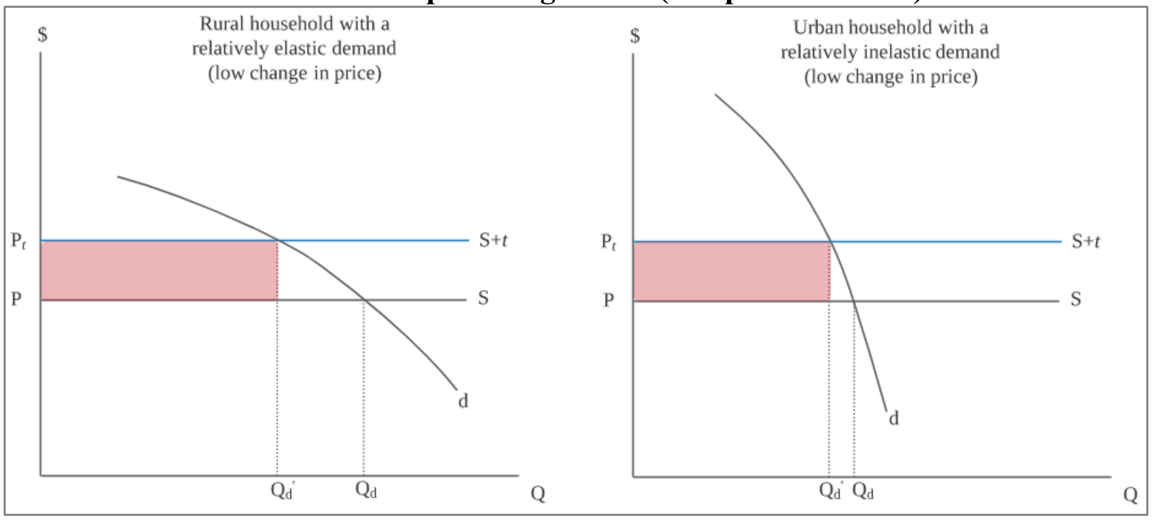


Note: The graphs above illustrate the *ceteris paribus* differential economic burden for households with varying sensitivity to changes in the price of gasoline. Before the TCI-P, each household is consuming Q_d gallons of gasoline at price P. When the supply curve shifts upward, the households on the left and right face the same price but choose to consume different quantities, Q_d'. The household on the left-hand side is shown to have a relatively elastic demand curve. Since rural households are thought to be more price sensitive (Spiller, Stephens, and Chen 2017), the left-hand side may be considered a rural household, while the right-hand side may be considered an urban household. *Ceteris paribus*, rural households are therefore expected to bear lower economic burdens from changes in the price of gasoline. Note that the supply curve facing each individual household is approaching infinite elasticity. In large markets, each individual consumer is expected to have virtually no influence over a good's price. In other words, the consumer is considered a "price taker" and can purchase any quantity of the good it wishes at the given price. Thus, to the individual consumer, the supply curve is assumed to be perfectly elastic.

phenomenon, while figure 10 shows how a sufficiently high price increase can counteract this initial difference in quantities demanded. All graphs are illustrative and are not meant to represent the true relative burdens faced by rural and urban households from the TCI-P.

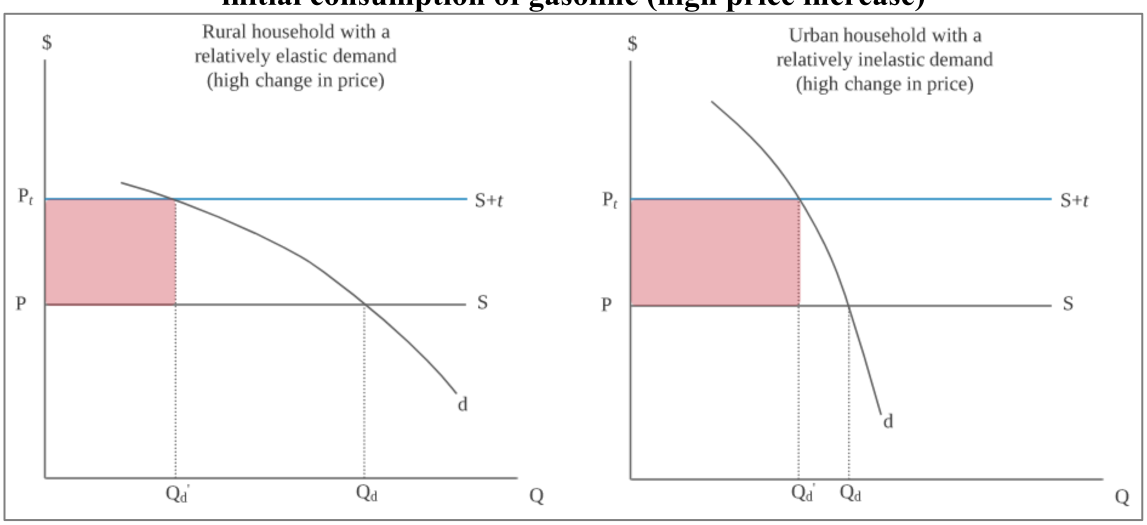
While relative price elasticities and quantities demanded can affect the nominal economic burdens faced by rural and urban households, comparing these values to rural and urban households' income may provide a more robust understanding of how changes in price can affect consumers' comparative wellbeing. For Maine households, the economic burden as a share of annual household income was found to be greater for rural

Figure 9. Economic burdens of rural versus urban households with varying initial consumption of gasoline (low price increase)



Note: The rural household (left-hand side) consumes more gasoline than the urban household (right-hand side), such that for the same low change in price, its nominal economic burden is greater.

Figure 10. Economic burdens of rural versus urban households with varying initial consumption of gasoline (high price increase)



Note: In figure 10 above, rural and urban before-tax quantities demanded of gasoline are the same as in figure 9. The only change is the relative size of the price increase, which in this case (and in the case of a 17¢ increase from the TCI-P) is large enough to cause urban households to once again experience a greater nominal economic burden, illustrated by the larger area of the red shaded region of the right-hand graph.

than for urban Maine, regardless of the price increase.

As tables 14 and 15 showed, the economic burden of the TCI-P is greater for rural than urban Maine, although the burden per household for the two regions is roughly the same at a price increase of 17¢. Even though rural households tend to consume more gasoline than urban households, they were also estimated by the present analysis to be more sensitive to changes in fuel prices. Therefore, at a price increase of 17¢ per gallon, rural households were estimated to reduce their consumption such that the economic burden they face is the same as (or slightly lower than) that of urban households. For comparison, in tables 14 and 15 I have expressed households' economic burdens as a percent of annual fuel costs and fuel taxes in columns 4 and 5, respectively. Note that in this case the burden as a percent of fuel costs and fuel taxes was estimated to be identical for urban and rural households due to the close annual burdens they face. My calculations show that for all price increases except 17¢, the average rural household would face higher fuel costs and fuel taxes than the average urban household. Therefore, percentages for all but the 17¢ increase in price are somewhat misleading.

The economic burden was also found to comprise a greater share of rural households' driving costs than the costs of urban households for all price increases except 17¢. For a 17¢ increase in the price of gasoline, the economic burden as a percent of driving costs for rural and urban households was virtually identical. Also of note, according to my estimates, the economic burden of the TCI-P comprised a much greater share of the costs of driving than did the economic loss. My estimates indicate that, when compared to the costs of driving, for both urban and rural households the economic burden of the TCI-P is relatively small. Assuming an annual VMT of 11,363 per vehicle per household, the economic burden of a 5¢ increase in the price of gasoline for urban households would comprise just 1.1% of variable driving costs for used vehicles and 0.6% of total costs for a used vehicle, compared to 1.1% and 0.6% for a rural household, respectively. These percentages are somewhat higher for a 17¢ price increase, for which the average Maine household was estimated to face economic burdens comprising up to 3.5% of variable costs for a used vehicle, 4.2% of fixed costs for a used vehicle, and 1.9% of total costs for a used vehicle. For a new vehicle, the economic burden of a 17¢ price increase as a percent of fixed and total costs for both urban and rural households would fall to 1.4% and 1.0%, respectively. For a full summary of my results, see tables E7 through E12 in appendix E.

3.4 Driving Costs by Vehicle Type

Not all households have identical preferences for vehicle make and model. Although the aggregate fuel economy in Maine is 21.8 MPG, this is only true on average. A household that owns hybrid vehicles, for example, would likely have an average fuel economy ranging from 30 to 50 MPG. An obvious consequence of this variance is differing fuel costs, but maintenance and ownership costs also vary by vehicle type (American Automobile Association 2019). For example, out of the nine vehicle types included in AAA's 2019 brochure, maintenance costs were generally shown to be highest for large sedans and lowest for electric vehicles, while ownership costs were highest for pickup trucks and lowest for small sedans (American Automobile Association 2019).

Table 16. Annual Driving Costs by Vehicle Type and VMT

Small sedan		Medium sedan		Large sedan		Small SUV	
VMT	Total costs (year)	VMT	Total costs (year)	VMT	Total costs (year)	VMT	Total costs (year)
10,000	$12,786	10,000	$15,761	10,000	$18,942	10,000	$15,240
12,500	$13,624	12,500	$16,676	12,500	$20,040	12,500	$16,157
15,000	$14,462	15,000	$17,591	15,000	$21,137	15,000	$17,074
11,363	$13,243	11,363	$16,260	11,363	$19,540	11,363	$15,740
Medium SUV		**Minivan**		**Pickup truck**		**Hybrid car**	
VMT	Total costs (year)	VMT	Total costs (year)	VMT	Total costs (year)	VMT	Total costs (year)
10,000	$18,596	10,000	$18,283	10,000	$19,571	10,000	$14,462
12,500	$19,719	12,500	$19,334	12,500	$20,770	12,500	$15,133
15,000	$20,843	15,000	$20,385	15,000	$21,969	15,000	$15,804
11,363	$19,208	11,363	$18,856	11,363	$20,225	11,363	$14,828

Note: This table shows the annual Maine household's total costs (variable plus fixed) of driving for eight different vehicle categories. Electric vehicles were excluded from the table since variable costs remained unchanged after adjustments to the price of fuel. The total costs for each vehicle were multiplied by the number of vehicles per household (2.06) to get total costs per household. Results apply to the driving costs of new vehicles only, including depreciation and finance costs.

Because of these differences in the costs of driving, it was necessary to analyze how the TCI-P might affect households that own, for example, minivans as opposed to pickup trucks.

My results are summarized in table 16. The Maine average household elasticity was calculated to be -0.87807 for a 9¢ increase in the price of gasoline. From this, the change in consumption was estimated to be -19,462,178 gallons for a statewide economic loss and burden of -$1,751,596 and $51,222,091, respectively. Per household, this amounts to approximately $3 in economic loss and $92 in economic burden annually, at least in the short run. I then divided each value by the total household costs of driving for each of the 36 combinations of vehicle type and VMT. Note that results are only representative of the costs of driving new vehicles with 2019 model years and depreciation and finance costs intact.

My results indicate that the economic loss associated with the TCI-P would comprise a similar share of the costs of driving for all vehicle types, regardless of VMT. The only exception is electric vehicles, which do not run on gasoline and would therefore result in no economic loss or burden from the TCI-P. For most vehicle types and VMT combinations, economic loss was found to comprise 0.0% of the costs of driving new vehicles. For electric vehicles, economic loss also comprised 0.0% of the costs of driving.

Results for the economic burden were more interesting. Overall, the economic burden was estimated to comprise the highest percent of driving costs for households that own small sedans and the lowest percent (aside from EVs) for households that own pickup trucks. This is because the costs of driving a pickup truck are higher than for any other vehicle, as shown in table 16 above. Of course, since electric vehicles do not run on gasoline, the economic burden was estimated to comprise 0.0% of the driving costs for households that own electric vehicles.[35] Importantly, households that own hybrid cars were shown to experience the second highest burden as a percent of the costs of driving. This is a result of hybrid vehicles' higher-than-average fuel economies and low total driving costs. Complete results are reported in table 17 below.

[35] Total driving costs for electric vehicles can be found in the American Automobile Association (2019).

Table 17. Economic Loss and Burden as a Percent of Driving Costs for Nine Vehicle Types

Economic loss and burden as a percent of households' driving costs (9¢ price increase)									
Economic loss (small sedans)					Economic burden (small sedans)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle		10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Percent of driving costs	0.0%	0.0%	0.0%	0.0%	Percent of driving costs	-0.7%	-0.7%	-0.6%	-0.7%
Economic loss (medium sedans)					Economic burden (medium sedans)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle		10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Percent of driving costs	0.0%	0.0%	0.0%	0.0%	Percent of driving costs	-0.6%	-0.6%	-0.5%	-0.6%
Economic loss (large sedans)					Economic burden (large sedans)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle		10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Percent of driving costs	0.0%	0.0%	0.0%	0.0%	Percent of driving costs	-0.5%	-0.5%	-0.4%	-0.5%
Economic loss (small SUVs)					Economic burden (small SUVs)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle		10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Percent of driving costs	0.0%	0.0%	0.0%	0.0%	Percent of driving costs	-0.6%	-0.6%	-0.5%	-0.6%
Economic loss (medium SUVs)					Economic burden (medium SUVs)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle		10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Percent of driving costs	0.0%	0.0%	0.0%	0.0%	Percent of driving costs	-0.5%	-0.5%	-0.4%	-0.5%
Economic loss (minivans)					Economic burden (minivans)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle		10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Percent of driving costs	0.0%	0.0%	0.0%	0.0%	Percent of driving costs	-0.5%	-0.5%	-0.5%	-0.5%
Economic loss (pickup trucks)					Economic burden (pickup trucks)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle		10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Percent of driving costs	0.0%	0.0%	0.0%	0.0%	Percent of driving costs	-0.5%	-0.4%	-0.4%	-0.5%
Economic loss (hybrid vehicles)					Economic burden (hybrid cars)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle		10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Percent of driving costs	0.0%	0.0%	0.0%	0.0%	Percent of driving costs	-0.6%	-0.6%	-0.6%	-0.6%
Economic loss (electric vehicles)					Economic burden (electric vehicles)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle		10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Percent of driving costs	0.0%	0.0%	0.0%	0.0%	Percent of driving costs	0.0%	0.0%	0.0%	0.0%

Note: Table 17 shows the economic loss and burden of a 9¢ increase in the price of gasoline for the average Maine household, expressed as a percent of the costs of driving 9 vehicle types.

CHAPTER IV

DISCUSSION & CONCLUSIONS

As the effects of climate change continue to intensify, policymakers have begun looking for solutions to this complex problem (MCC 2020). The TCI-P remains one option among many, although concerns have been raised that rural Mainers, in particular, will be adversely affected by changes in the price of gasoline. The present research explores the potential heterogeneous impacts the TCI-P might have on rural and urban Mainers by testing the following hypotheses: (1) rural households are more elastic to changes in the price of gasoline, and (2) rural households will be disproportionately affected by the TCI-P.

Results indicated support for the first hypothesis, as rural households (η = -0.97) in Maine were indeed shown to be more price elastic than urban households (η = -0.75). Building off of these results, I estimated reductions in households' consumption of gasoline in both regions, showing that rural households will reduce consumption by a greater amount than urban households. Despite this fact, rural households were still shown to experience a greater economic loss and burden than urban households for either a 5¢ or 9¢ increase in the price of gasoline, consistent with the second hypothesis. However, given a 17¢ increase in price, rural households were shown to consume less gasoline than urban households, thereby facing a somewhat smaller economic burden. This result was unexpected but not unusual given the properties of the price elasticity of demand illustrated in figures 8 through 10 above. Nevertheless, since the latest modeling results for the TCI-P predicted no more than a 9¢ increase in the price of gasoline, rural households are expected to face higher economic burdens.

4. High Elasticity Estimates

The short-run price elasticities presented in this analysis are high by most standards. Traditionally, most short-run estimates of the price elasticity of demand for gasoline fall between -0.2 and -0.3 (Ajanovic, Dahl, and Schipper 2012; Basso and Oum 2007; Graham and Glaister 2002), whereas the estimates given in the present research ranged from approximately -0.74 to -0.97. As explained above, price elasticity of demand estimates for rural and urban Maine were adapted from Spiller, Stephens, and Chen (2017), who provided at least four reasons for these higher-than-average estimates. For one, the authors of this study used cross-sectional and household-level data, both of which tend to produce higher estimates (Spiller, Stephens, and Chen 2017). Second, the authors explained that their model "disaggregates" the choice set, which leads to higher estimates than studies for which choices are aggregated (Spiller, Stephens, and Chen 2017). In other words, rather than modeling a household's ability to switch from one vehicle type to another (e.g., from an SUV to a hatchback), the authors modeled an infinite number of potential switches (e.g., from a 2006 Toyota Prius to a 2009 Nissan Altima). When incorporated into their vehicle optimization equation, this disaggregation provided a more accurate representation of the real world, while having the effect of raising the elasticity estimate (Spiller, Stephens, and Chen 2017). Third, elasticity estimates were higher because the model included interaction parameters between household and vehicle characteristics. For example, household size was interacted with vehicle size, distance to MSA was interacted with MPG, and median income was interacted with vehicle age, among other variables. Failing to interact these characteristics in similar models results in less elastic estimates of the price elasticity of demand for gasoline. Finally, elasticities were higher than usual because the authors incorporated a fixed-effect coefficient in their utility specification to reflect the impact that certain vehicle characteristics (e.g., leather seats or chrome interior trim) have on a household's vehicle optimization process. Incorporating these fixed effects could have also potentially raised elasticity estimates. Thus, even though Maine estimates are higher than what is typically found in the literature, the data and modeling techniques used by Spiller, Stephens, and Chen (2017) account for these discrepancies.

It is also true that the adapted Maine average elasticity estimate (-0.87) is higher than the average given by Spiller, Stephens, and Chen (2017) (-0.74). This is consistent with Dahl (2012), who found considerable geographic variation in the price elasticities of over 70 world countries. For example, Colombia was found to have an intermediate-run price elasticity of demand for gasoline of -0.04, while Taiwan's was estimated to be -0.69. The difference between the Maine average and the average given by Spiller, Stephens, and Chen (2017) falls well within this range of variability.

Wadud, Graham, and Noland (2010) provided further empirical support for the elasticity estimates in the present research. In this study, the authors compiled a list of studies using household data and found that short-run elasticity estimates ranged from 0.00 to -1.33, but usually fell between -0.43 and -0.67 (Wadud, Graham, and Noland 2010). The higher mean estimate of Spiller, Stephens, and Chen (2017) is likely due to their modeling techniques. Even still, the adapted elasticity estimate for Maine (-0.87) is somewhat higher than their average (-0.74), due especially to the "rural or urban" and "distance to MSA" characteristics, which were estimated to have respective elasticities of -0.98 and -2.51 for rural Maine. It was these extreme values that had the effect of pulling up the statewide average.

Another reason for Maine's particularly high estimates may be the weights assigned to each household characteristic. Given the unique and novel approach of Spiller, Stephens, and Chen (2017), little if any research exists regarding which characteristics are more important than others in determining household demand for gasoline. In the present research, most characteristics were assigned equal weights except "household size" and "distance to MSA," which received lower weights. Had these characteristics been weighted differently, it is possible elasticity estimates would have been lower. For example, if the price of gasoline is the most important determinant of household elasticity, then the characteristic should have received greater weight, which would have lowered elasticity estimates.

4.1 Policy Implications

4.1.1 Implications for Maine's Emission Reduction Goals

In 2019, the 129th Maine state legislature enacted legislative document (LD) 1679, "An Act to Promote Clean Energy Jobs and to Establish the Maine Climate Council" (codified as 38 M.R.S.A. §577-A). This legislation tasked the Board of Environmental Protection to design rules that reduce the state's GHG emissions by 45% by 2030 and by 80% by 2050. Furthermore, it stipulated that the rules must be consistent with the goals of the Plan. Although the Plan did not call for entrance into the TCI-P, it is important to understand how the TCI-P could contribute to the state's emissions reduction goals should Maine become a signatory at some later date.

The transportation sector accounts for 54% of statewide emissions (Taylor and Cushman 2020). Approximately 59% of transportation emissions come from light-duty cars and trucks (Taylor and Cushman 2020),[36] the vehicles households are most likely to drive. Finally, an additional 97.9% come from household gasoline emissions (as opposed to diesel emissions). This means household vehicles that run on gasoline account for approximately 31% of statewide emissions.[37] Earlier, I reported that the TCI-P could result in a decline in household gasoline emissions of approximately 1.8% to 3.3% for a 5¢ to 9¢ increase in the price of gasoline, respectively. These figures represent just 0.6% to 1.0% of economy-wide emissions, a small share of Maine's 45% and 80% emissions reduction goals.

It is important to be precise about what these numbers mean. The TCI-P would result in more than just households reducing consumption of gasoline. It would also result in reductions in household diesel consumption, as well as the reduced consumption of commercial vehicles, municipal vehicles, and other vehicles operating on motor fuel or on-road diesel fuel (Transportation and Climate Initiative 2020). Therefore, the TCI-P would result in higher emission reductions than those shown in the present analysis. Without knowing the respective price elasticities of demand for gasoline and diesel, however, it is impossible to know exactly to what extent the owners of these vehicle types would reduce their consumption.

[36] I have assumed that motorcycles are included in this total.
[37] $.59 \times .54 \times .98 \times 100\% \approx 31\%$.

4.1.2 Implications for Maine's Transportation Goals

In the Plan recently released by the MCC, eight different strategies were created to help meet Maine's GHG emissions reduction goals. The first of these strategies, Strategy A, focused on reducing CO_2 emissions in the transportation sector by way of three proposals: (1) expanding the electric vehicle (EV) fleet, (2) raising the average fuel-economy of the vehicle fleet and expanding the use of alternative fuels, and (3) lowering VMT (MCC 2020). Each of these proposals would work in congruence with TCI-P goals of reducing emissions in the transportation sector.

As part of its proposal to expand the fleet of EVs in Maine, the MCC set a target of 219,000 light-duty EVs by 2030 (MCC 2020). To incentivize consumers to purchase these vehicles, the proposal suggested providing rebates to Maine households, particularly to those with low to moderate incomes (MCC 2020). Recognizing the state's shortage of funds for such an incentive program, the MCC expressed the need for innovative financing options. The second proposal (raising the average fuel-economy) contained a similar incentive program for non-EVs (MCC 2020), which, if enacted, would strain the state's financial resources even further. Finally, as part of its third policy proposal, the MCC set a goal to cut the VMT of light-duty vehicles by 20% by 2030 (MCC 2020). To do this, the Plan emphasized increasing Maine households' access to broadband internet services (MCC 2020). This would allow more families to work from home (MCC 2020). The proposal also suggested increasing subsidies for public transit and building more compact cities and towns so that, with the installation of active mobility infrastructure, low-carbon transportation options would become more accessible to those living in rural areas (MCC 2020).

Each of these proposals is consistent with TCI-P goals and complements program design. The final MOU provided that investments may be used for any and all "clean transportation projects and programs" selected by the participating jurisdictions, so long as they contribute to the equitable distribution of benefits and costs (Transportation and Climate Initiative 2020, 3). All three of the MCC's proposals, at least in theory, would meet these criteria. Furthermore, most of the MCC's policy priorities would work to minimize the worst cost impacts of the TCI-P. For example, the expansion of EVs would reduce households' demand for gasoline, and as a result, reduce fuel suppliers' demand for allowances. Allowance prices, as well as the price of gasoline, would fall, thereby minimizing the disproportionate cost burden of the TCI-P for low-income households. Similarly, expanding access to public transit or installing active mobility infrastructure would reduce the number of personal VMTs, resulting in less consumption of gasoline. The price effects on gasoline and allowances would be the same in this case as in the case of EV expansion and would further serve to minimize the disproportionate costs of the TCI-P for rural households.

These transportation projects will require additional funding from the state's transportation budget, which is already experiencing annual shortfalls. According to a report from the Eastern Research Group (ERG), Maine currently has annual funding shortages of approximately $232.00 million (Eastern Research Group 2020). This means that the MCC must find innovative funding solutions in order to make its policy proposals actionable. While the Plan did identify various funding options, most are not sustainable in the long run. For example, the Plan's short run funding solutions included borrowing money through general-fund bonds, establishing new funds, redirecting money from existing funds, and applying for federal grants (MCC 2020). Recognizing the limitations of these solutions, the MCC set a goal to reconvene in 2021 to brainstorm additional funding options (MCC 2020). It is possible, given the TWG's recommendation to monitor the TCI-P (MCC 2020), that the TCI-P will be presented once again in these discussion sessions as a partial funding solution.

The TCI-P could contribute valuable funding to help Maine meet its transportation goals. Even following reductions in state tax revenues, my estimates showed that the TCI-P would generate net gains to the Maine economy. The latest modeling results for the TCI-P estimated that allowance prices would start at \$6.60 (GCC 2020b). Therefore, based on the results given above, if the price of gasoline were to rise by 5¢ per gallon, Maine would see a short-term annual revenue stream of approximately \$32.44 million from allowances covering household consumption alone (i.e., not including the additional allowances fuel suppliers would need to hold to cover the affected fuel of other vehicles such as heavy-duty trucks or commercial vehicles). If the price of gasoline were to rise by 9¢ per gallon, this number would fall to roughly \$31.95 million. Subtracting losses in state tax revenues, Maine would see an annual, short-term net revenue gain of approximately \$29.20 million and \$26.11 million given a 5¢ or 9¢ increase in the price of gasoline, respectively. These figures apply to revenues from household consumption only.

It is important to note that TCI-P revenues largely depend on the quantity demanded of gasoline. If the quantity demanded is particularly low, for example due to investments in electric vehicles or public transit, then revenues from the TCI-P may not remain constant over time. In spite of this, my research indicated that the TCI-P could contribute valuable resources (at least in the short run) at a time when the state of Maine is in dire need of creative funding solutions.

4.1.3 Implications for Public Acceptance

At the time of this writing, Maine's governor had expressed no intention of joining the TCI-P. However, should the Mills administration change its position on the TCI-P, or should a new governor be elected in November 2022, the state must be prepared for these contingencies. Therefore, a comprehensive assessment of the overlaps and mismatches between public opinion and TCI-P modeling will help policymakers address roadblocks to public acceptance should joining the TCI-P become a policy priority in the future. When comparing public opinion to the results of the present research, both overlaps and mismatches are apparent.

Public concerns surrounding the TCI-P have revolved around its expected impacts on industry and low-income households. While the present research does not directly address the TCI's impacts on the logging and trucking industries in Maine, it can provide some limited insights into how they may be affected. From the previous illustrations on the potential heterogeneous impacts of the TCI-P given above, it is clear that the greater the quantity of motor fuel consumed, the higher the absolute value of the economic burden. This explains the fact that rural households were estimated to experience greater economic burdens than urban households for price increases of 5¢ or 9¢. Furthermore, this fact suggests that the logging and trucking industries in the northern part of the state may indeed be disproportionately affected by the TCI-P to the extent that their VMTs exceed that of industries in the southern part of the state. Previous illustrations of the economic burden also revealed that, *ceteris paribus*, a given change in price would create a greater economic burden in those with lower price elasticities of demand than it would for those with higher price elasticities of demand. It was not an objective of the present research to determine how the industry price elasticities of demand for motor fuel vary across the state, but given that price elasticity is one determinant of the economic burden, obtaining this information would be an important first step in determining future policies to address public acceptance for these industries.

The profit margins of these industries are another factor to consider regarding the relative economic burden of the TCI-P in rural and urban Maine. To the extent higher economic burdens entail net increases in gasoline expenditures (which may not always be the case), industries that operate on thin profit margins (e.g., the trucking industry) may be disproportionately affected.

4.1.4 Policy Recommendations

4.1.4.1 Investments. As implied in subsections 4.1.2 and 4.1.3, the state must seek to advance its transportation goals while ensuring the equitable distribution of benefits and costs. If Maine chooses to become a signatory to the TCI-P in the future, investments can be used to accomplish both objectives. According to the Plan, the state's top three transportation goals include expanding electric vehicles, raising the average fuel economy of the vehicle fleet, and reducing VMTs (MCC 2020). Electrification of light-duty private vehicles is one of the key ways Maine can meet its GHG reduction goals (Taylor and Cushman 2020). Research suggests a $2,000 rebate would be needed for EVs to achieve price parity with internal combustion engines (ICEs) over a decade of use (ERG 2020). In addition, Maine needs to significantly expand its charging infrastructure in order for households to feel comfortable shifting to EVs (ERG 2020). This is especially true in rural Maine (ERG 2020), and therefore prioritizing investments in rebates and charging infrastructure in this region would be one way to meet the TCI-P's 35% equity mandate. Expanding the light-duty EV fleet would also contribute to at least three of the TCI-P's goals, including reducing CO_2 emissions, improving air quality, and making clean transportation affordable (Transportation and Climate Initiative 2020).

In addition to EV rebates, the Plan also called for investing in rebates for more fuel-efficient vehicles as a way to raise the average fuel economy of the vehicle fleet (MCC 2020). This may prove a superior investment option for rural Maine in particular, since the population density is more diffuse and building charging infrastructure may not be as cost-effective. This investment option would also contribute to the TCI-P goals of reducing GHG emissions, advancing equity, improving accessibility to low-emission transportation, and reducing harmful air pollutants (Transportation and Climate Initiative 2020).

To reduce VMTs, the Plan emphasized increasing access to broadband, expanding public transit, and consolidating communities (MCC 2020). The present research showed that rural households drive more than urban households. Therefore, investing in strategies to reduce VMT has the potential to provide greater benefits to rural Maine, which would contribute to the TCI-P's 35% equity mandate. Since rural counties face the lowest broadband access (BroadbandNow 2021), expanding broadband would help distribute TCI-P benefits in an equitable way. The Plan also proposed expanding public transit (MCC 2020), which might involve increasing the scope of bus and rail services throughout the state of Maine. This strategy would contribute to the TCI-P's goal of reducing CO_2 emissions by reducing the use of private vehicles (Transportation and

Climate Initiative 2020). It would also be consistent with the TCI-P's goal of making clean transportation more affordable (Transportation and Climate Initiative 2020), which could advance equity goals. Finally, the Plan called for consolidating communities (MCC 2020), which may result in developing priority growth areas (Taylor and Cushman 2020). This would mean investing in downtown areas and constructing complete streets and walking trails so that most things consumers need are accessible within walking or biking distance (Taylor and Cushman 2020). This strategy would contribute to the TCI-P's goals of improving air quality and public health, while reducing CO_2 emissions from unnecessary VMT (Transportation and Climate Initiative 2020).

4.1.4.2 Messaging and Communication. Ensuring the Maine public is informed about statewide policy decisions, especially those that could affect citizens differently, is a first step toward public acceptance. If the TCI-P is adopted in Maine, information campaigns should address the following areas:

1. Price changes: information campaigns should be transparent about the degree of price fluctuation that may result from the TCI-P, comparing this to year-to-year fluctuations in fuel prices at the state or national levels. For example, data from annual gasoline price averages at the national level show that a 5¢ to 9¢ change in the price of gasoline (the range expected from the TCI-P) would fall well within the normal range of year-to-year price fluctuations (Statista Research Department 2021).
2. Equity impacts: my results indicated rural households will experience a disproportionate economic burden from the TCI-P. Information campaigns should state these results clearly, while emphasizing the relative size of the disparity

between rural and urban Maine in relation to household income, fuel costs and taxes, and the costs of driving for different parts of the state.

3. Investment decisions: the public's perceptions surrounding how revenues are invested will be important to the political success or failure of the TCI-P—perhaps as important as the investments themselves. Therefore, information campaigns should communicate clearly the intent of the state to distribute TCI-P proceeds in accordance with the 35% equity mandate. Furthermore, messages should clarify how revenues will be invested and the direct financial impacts of these investments on different sections of the population. Messages should also communicate the cost-effectiveness and GHG emissions reduction potential of chosen investments.
4. Transparency: information campaigns should be specific about the emissions reductions expected from the TCI-P. While the TCI-P will achieve 26% emissions reductions in participating jurisdictions by 2032, 24.3 of these percentage points arise from fundamental changes to the transportation sector that will occur regardless of whether the TCI-P is implemented or not (GCC 2020b). Burying, obfuscating, or not revealing this detail in information campaigns would betray public trust in the TCI-P.
5. Program benefits: information campaigns should also be specific about the potential benefits of the TCI-P, such as improvements in public health, job growth, and reduced climate impacts, taking care to report only those benefits expected to accrue to Mainers.

Messages must be accompanied by effective communication strategies. The following are a series of guidelines that can be followed to make communication strategies more effective: (1) appeal to social norms and share stories about how these norms affect behavior in local communities, (2) make climate change relevant today, and (3) provide examples of simple actions people can take immediately. On the first point, research shows that individuals are more likely to act when they know others are acting, too (Stoknes 2017). In other words, communicating messages about social norms can be an effective way to spur more climate-friendly behaviors. A particularly good way to do this may be through storytelling (Stoknes 2017). Information campaigns can describe personal, relatable stories about members of the community that are participating in a TCI-P investment, such as a rebate program or the creation of a new bus line. Research also shows that people find it difficult to respond to events that seem distant and unknown, such as climate change (Stoknes 2017). Communication strategies should therefore make climate change salient now. In other words, they should focus on impacts Mainers are facing on a day-to-day basis (e.g., warming waters and the increased prevalence of winter ticks). This focus on immediate impacts might best be paired with messages about immediate and simple solutions that Mainers can take to combat these impacts (Stoknes 2017). For example, TCI-P investments in public transit could make buses and trains simple, easy, and affordable alternatives to driving personal vehicles.

Beyond these three guidelines, policymakers and public relations specialists should pay special attention to framing (Boykoff 2011; Stoknes 2017), verbiage, and the frequency with which messages are communicated (Boykoff 2011). Framing involves highlighting particular aspects of a climate change issue and making them appear more important (Boykoff 2011). The verbiage used in climate change messages is also important. Maxwell Boykoff (2011) cautioned against the use of scientific jargon and recommended that communicators research how the use of certain terms may be interpreted differently than others. For example, research has shown that the terms “climate change” and “global warming” are perceived by the public to have different meanings and invoke different emotions. Furthermore, the frequency and visibility of messaging on climate change issues can impact the creation of public policy (Boykoff 2011).

Another important issue related to communications on climate change is the use of digital images. Climate Visuals (n.d.) recommended 7 principles for the dissemination of climate change images, some of which echo recommendations already made above (e.g. visual storytelling and highlighting local and immediate impacts of climate change). Climate Visuals also suggested targeting images at ideologically and politically likeminded groups of people, appealing to emotions, and showing images of real people being impacted by the effects of climate change (n.d.).

4.2 Study Limitations and Recommendations for Future Research

There were two primary study limitations that affected my results. The first was unavailable or imperfect data. Adapting elasticities for rural and urban Maine required collecting demographic and other data for each Maine county. However, I could not find county-by-county data on gasoline prices for the appropriate year, the average number of vehicles per household, or the average fuel economy. Thus, I held the statewide averages for these characteristics as fixed across rural and urban Maine, which undoubtedly affected price elasticity estimates in both regions. Another data limitation was the existence of multiple VMT estimates (one from the DOT and one from the MCC), which produced different fuel economy estimates. Ultimately, I chose to use the VMT estimate from the Maine DOT, as explained in section 2.1.

Another study limitation was that, in calculating the various household characteristics, I was forced to incorporate a limited amount of diesel consumption. Clearly, the price elasticity of demand for gasoline does not depend on the consumption of diesel fuel. However, without incorporating diesel consumption, certain estimates of household characteristics would have been biased. For example, estimating fuel economy required a VMT estimate, an estimate of the number of licensed drivers per household, and fuel consumption data. Because I could not differentiate between the number of licensed drivers of gasoline vehicles as opposed to diesel vehicles, I had to combine them, which meant incorporating diesel fuel as well. However, since approximately 97.9% of all household vehicle emissions come from gasoline, the bias resulting from this data limitation was likely small.

As mentioned above, my estimates regarding changes in the quantity demanded of gasoline relied on fuel consumption data from a Maine DEP database. The database divided gasoline consumption into 11 categories (combination short-haul trucks, light commercial trucks, etc.). Three of these categories—motorcycles, passenger cars, and passenger trucks—were used as a proxy for true household gasoline consumption, since no other data was available. Because of this, it is possible that some of the vehicles I considered to be household vehicles were in fact not household vehicles, which could have resulted in a slight overestimation. Still, even if this was the case, the overestimation would have been relatively small.

The second study limitation arose from the estimating approach used by Spiller, Stephens, and Chen (2017). Because this approach was novel, and because little if any literature exists separating the price elasticity of demand for gasoline into the same eight characteristics, I was not sure of the appropriate weights to assign to each household characteristic. Indeed, Spiller, Stephens, and Chen (2017) weighted all characteristics equally. However, if the price of gasoline had been given a greater weight (e.g., 30% instead of 13.5%), the average price elasticity of demand for gasoline could have been significantly lower. My weight assignation was based on assumptions of the relative importance of household characteristics inferred from the scant literature on this topic. While I used a conservative weighting scheme, it is nevertheless certain that elasticity estimates would have varied had the weighting scheme been different. Clearly, future research should be done to determine the relative importance of various household characteristics in determining a household's price elasticity of demand for gasoline.

Future research should also conduct a more detailed study of the price elasticity of demand for gasoline across various demographic groups in Maine. The present research, while a good starting point, lacks the precision of sound econometric analyses. In this same vein, research should attempt to quantify the potential effects of the TCI-P on Maine industry, particularly the logging and trucking industries. This would provide a better sense of both the roadblocks to public acceptance of the TCI-P and the investment avenues that would most equitably distribute benefits and costs.

In addition, more research is needed to determine the most effective messaging and communication strategies for a Maine audience, should the state choose to join the TCI-P at some later date. Researchers should also consider conducting further public opinion polling across specific demographics, since information is lacking in this area. Having greater knowledge of Mainers' perceptions or concerns surrounding the TCI-P will give policymakers and public relations specialists an idea of how to target messages; how to tell meaningful stories; and what framing, verbiage, and images to use while telling them.

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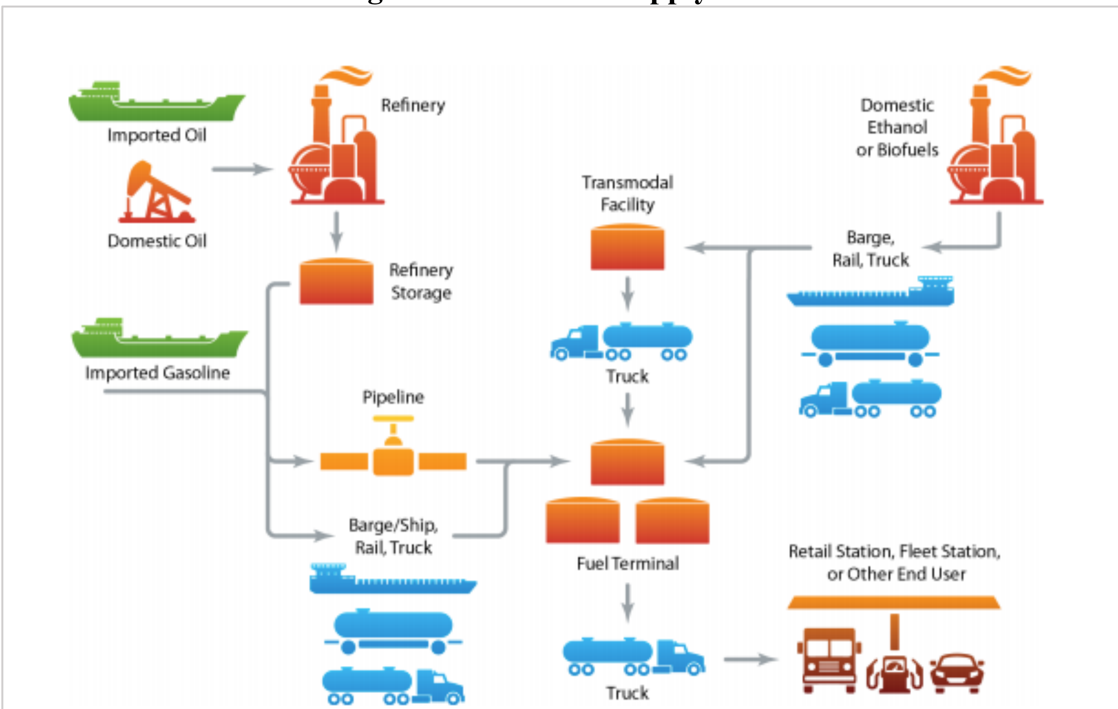
APPENDICES

APPENDIX A: GASOLINE SUPPLY CHAIN

Figure A1. Gasoline supply chain



Source: National Renewable Energy Laboratory report, "High Octane Fuel: Terminal Backgrounder," (Moriarty 2016, 2).

APPENDIX B: PRICE ELASTICITY OF GASOLINE DEMAND

Table B1. Price elasticity of gasoline demand by household characteristic

Variable		Average Elasticity (SD)
Household Size	1 or 2	−0.679 (.653)
	3 or 4	−0.899 (.805)
	5+	−0.947 (.868)
Number of vehicles	1	−0.416 (.343)
	2	−0.815 (.654)
	3+	−1.35 (1.05)
Average MPG	<=23	−0.856 (.783)
	23:30	−0.739 (.703)
	30+	−0.619 (.614)
Distance to MSA	<=17 km	−0.258 (.173)
	18:55 km	−0.624 (.408)
	56 km+	−1.45 (.951)
Gasoline price	<=$1.90	−0.425 (.371)
	$1.90:$3.70	−0.747 (.717)
	$3.70+	−0.989 (.802)
Average Commute Time	<=10 min	−0.711 (.695)
	10:20 min	−0.802 (.740)
	20 min+	−0.842 (.747)
Household Income	<=$45,000	−0.638 (.624)
	$45,000:$75,000	−0.764 (.736)
	$75,000+	−0.847 (.765)
Rural	Yes	−0.978 (.817)
	No	−0.659 (.649)

Source: "Understanding the heterogeneous effects of gasoline taxes across income and location," (Spiller, Stephens, and Chen 2017, 84).

APPENDIX C: TABLES ON ELASTICITY CALCULATIONS

Table C1. Statewide price elasticity calculations by household characteristics

		Elasticity estimate	Difference	%Change in elasticity	Household characteristic used	Difference used	Elasticity used	%Change in elasticity used	Maine average
Household size	1.5	-0.679							2.33
	3.5	-0.899	2	32.4%					0.83
	5	-0.947	1.5	5.3%	1.5	2	-0.679	32.4%	0.415
									-0.7703
Number of vehicles	1	-0.416							2.06
	2	-0.815	1	95.9%					0.06
	3	-1.35	1	65.6%	2	1	-0.815	65.6%	0.06
									-0.8471
Average MPG	</=23	-0.856		15.8%					21.76
	26.5	-0.739	3.5	19.4%					4.74
	>/=30	-0.619	3.5		26.5	3.5	-0.739	15.8%	1.354285714
									-0.897451429
Distance to MSA	</=17 km	-0.258							59.99
	36.5 km	-0.624	19.5	141.9%					23.49
	>/= 56 km	-1.45	19.5	132.4%	36.5	19.5	-0.624	132.4%	1.204615385
									-1.619012308
Gasoline price	</=$1.90	-0.425							2.39
	$2.80	-0.747	0.9	75.8%					0.49
	>/=$3.70	-0.989	0.9	32.4%	1.9	0.9	-0.425	75.8%	0.544444444
									-0.600311111
Commute time	</=10 min	-0.711							24
	15 min.	-0.802	5	-12.8%					9
	>/=20 min.	-0.842	5	5.0%	15	5	-0.802	5.0%	1.8
									-0.874
Median income	</=$45,000	-0.638							55425
	$60,000	-0.764	$15,000	19.7%					10425
	>/=$75,000	-0.847	$15,000	10.9%	45000	15,000	-0.638	19.7%	0.695
									-0.72557

Table C2. Rural Maine price elasticity calculations by household characteristic

		Elasticity estimate	Difference	%Change in elasticity	Household characteristic used	Difference used	Elasticity used	%Change in elasticity used	Rural
Household size	1.5	-0.679							2.32
	3.5	-0.899	2	32.4%					0.82
	5	-0.947	1.5	5.3%	1.5	2	-0.679	32.4%	0.41
									-0.7692
Number of vehicles	1	-0.416							2.06
	2	-0.815	1	95.9%					0.06
	3	-1.35	1	65.6%	2	1	-0.815	65.6%	0.06
									-0.8471
Average MPG	</=23	-0.856		15.8%					21.76
	26.5	-0.739	3.5	19.4%					4.74
	>/=30	-0.619	3.5		26.5	3.5	-0.739	15.8%	1.354285714
									-0.897451429
Distance to MSA	</=17 km	-0.258							80.97
	36.5 km	-0.624	19.5	141.9%					44.47
	>/= 56 km	-1.45	19.5	132.4%	36.5	19.5	-0.624	132.4%	2.280512821
									-2.50770359
Gasoline price	</=$1.90	-0.425							2.39
	$2.80	-0.747	0.9	75.8%					0.49
	>/=$3.70	-0.989	0.9	32.4%	1.9	0.9	-0.425	75.8%	0.544444444
									-0.600311111
Commute time	</=10 min	-0.711							24.73
	15 min.	-0.802	5	-12.8%					9.73
	>/=20 min.	-0.842	5	5.0%	15	5	-0.802	5.0%	1.946
									-0.87984
Median income	</=$45,000	-0.638							53701
	$60,000	-0.764	$15,000	19.7%					8701
	>/=$75,000	-0.847	$15,000	10.9%	45000	15,000	-0.638	19.7%	0.580066667
									-0.7110884

Table C3. Urban Maine price elasticity calculations by household characteristic

		Elasticity estimate	Difference	%Change in elasticity	Household characteristic used	Difference used	Elasticity used	%Change in elasticity used	Urban
Household size	1.5	-0.679							2.35
	3.5	-0.899	2	32.4%					0.85
	5	-0.947	1.5	5.3%	1.5	2	-0.679	32.4%	0.425
									-0.7725
Number of vehicles	1	-0.416							2.06
	2	-0.815	1	95.9%					0.06
	3	-1.35	1	65.6%	2	1	-0.815	65.6%	0.06
									-0.8471
Average MPG	</=23	-0.856		15.8%					21.76
	26.5	-0.739	3.5	19.4%					4.74
	>/=30	-0.619	3.5		26.5	3.5	-0.739	15.8%	1.354285714
									-0.897451429
Distance to MSA	</=17 km	-0.258							30.16
	36.5 km	-0.624	19.5	141.9%					13.16
	>/= 56 km	-1.45	19.5	132.4%	17	19.5	-0.258	141.9%	0.674871795
									-0.505003077
Gasoline price	</=$1.90	-0.425							2.39
	$2.80	-0.747	0.9	75.8%					0.49
	>/=$3.70	-0.989	0.9	32.4%	1.9	0.9	-0.425	75.8%	0.544444444
									-0.600311111
Commute time	</=10 min	-0.711							22.96
	15 min.	-0.802	5	-12.8%					7.96
	>/=20 min.	-0.842	5	5.0%	15	5	-0.802	5.0%	1.592
									-0.86568
Median income	</=$45,000	-0.638							60571
	$60,000	-0.764	$15,000	19.7%					571
	>/=$75,000	-0.847	$15,000	10.9%	60000	15000	-0.764	10.9%	0.038066667
									-0.767159533

APPENDIX D: EXCEL CALCULATIONS

https://drive.google.com/file/d/1iAKAeNJlZ9iHlTlnQSIvCkYHtFyF53CF/view?usp=sharing

APPENDIX E: TABLES ON ECONOMIC LOSSES AND BURDENS

Table E1. Economic losses faced by urban households from a 5-cent increase in the price of gasoline expressed as a percent of average driving costs

Loss per household (5 cent increase) as a percent of driving costs (urban)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Variable (used)	-0.02%	-0.02%	-0.01%	-0.02%
Variable (new)	-0.02%	-0.02%	-0.01%	-0.02%
Fixed (new)	-0.01%	-0.01%	-0.01%	-0.01%
Fixed (no depreciation or finance)	-0.02%	-0.02%	-0.02%	-0.02%
Total for new vehicles	-0.01%	0.00%	0.00%	0.00%
Total for average Maine vehicles	-0.01%	-0.01%	-0.01%	-0.01%

Table E2. Economic losses faced by rural households from a 5-cent increase in the price of gasoline expressed as a percent of average driving costs

Loss per household (5 cent increase) as a percent of driving costs (rural)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Variable (used)	-0.03%	-0.02%	-0.02%	-0.02%
Variable (new)	-0.03%	-0.02%	-0.02%	-0.02%
Fixed (new)	-0.01%	-0.01%	-0.01%	-0.01%
Fixed (no depreciation or finance)	-0.03%	-0.03%	-0.03%	-0.03%
Total for new vehicles	-0.01%	-0.01%	-0.01%	-0.01%
Total for average Maine vehicles	-0.01%	-0.01%	-0.01%	-0.01%

Table E3. Economic losses faced by urban households from a 9-cent increase in the price of gasoline expressed as a percent of average driving costs

Loss per household (9 cent increase) as a percent of driving costs (urban)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Variable (used)	-0.06%	-0.05%	-0.04%	-0.06%
Variable (new)	-0.07%	-0.05%	-0.04%	-0.06%
Fixed (new)	-0.02%	-0.02%	-0.02%	-0.02%
Fixed (no depreciation or finance)	-0.07%	-0.07%	-0.07%	-0.07%
Total for new vehicles	-0.02%	-0.02%	-0.01%	-0.02%
Total for average Maine vehicles	-0.03%	-0.03%	-0.03%	-0.03%

Table E4. Economic losses faced by rural households from a 9-cent increase in the price of gasoline expressed as a percent of average driving costs

Loss per household (9 cent increase) as a percent of driving costs (rural)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Variable (used)	-0.08%	-0.07%	-0.06%	-0.07%
Variable (new)	-0.09%	-0.07%	-0.06%	-0.08%
Fixed (new)	-0.03%	-0.03%	-0.03%	-0.03%
Fixed (no depreciation or finance)	-0.09%	-0.09%	-0.09%	-0.09%
Total for new vehicles	-0.02%	-0.02%	-0.02%	-0.02%
Total for average Maine vehicles	-0.04%	-0.04%	-0.03%	-0.04%

Table E5. Economic losses faced by urban households from a 17-cent increase in the price of gasoline expressed as a percent of average driving costs

Loss per household (17 cent increase) as a percent of driving costs (urban)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Variable (used)	-0.22%	-0.18%	-0.15%	-0.20%
Variable (new)	-0.23%	-0.19%	-0.15%	-0.20%
Fixed (new)	-0.08%	-0.08%	-0.07%	-0.08%
Fixed (no depreciation or finance)	-0.24%	-0.24%	-0.24%	-0.24%
Total for new vehicles	-0.06%	-0.06%	-0.05%	-0.06%
Total for average Maine vehicles	-0.12%	-0.10%	-0.09%	-0.11%

Table E6. Economic losses faced by rural households from a 17-cent increase in the price of gasoline expressed as a percent of average driving costs

Loss per household (17 cent increase) as a percent of driving costs (rural)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Variable (used)	-0.30%	-0.24%	-0.20%	-0.26%
Variable (new)	-0.31%	-0.25%	-0.20%	-0.27%
Fixed (new)	-0.10%	-0.10%	-0.10%	-0.10%
Fixed (no depreciation or finance)	-0.32%	-0.32%	-0.32%	-0.32%
Total for new vehicles	-0.08%	-0.07%	-0.07%	-0.08%
Total for average Maine vehicles	-0.15%	-0.14%	-0.12%	-0.14%

Table E7. Economic burdens faced by urban households from a 5-cent increase in the price of gasoline expressed as a percent of average driving costs

Burden per household (5 cent increase) as a percent of driving costs (urban)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Variable (used)	1.24%	0.99%	0.83%	1.09%
Variable (new)	1.28%	1.03%	0.85%	1.13%
Fixed (new)	0.43%	0.43%	0.40%	0.43%
Fixed (no depreciation or finance)	1.28%	1.28%	1.28%	1.28%
Total for new vehicles	0.32%	0.30%	0.27%	0.31%
Total for average Maine vehicles	0.63%	0.56%	0.50%	0.59%

Table E8. Economic burdens faced by rural households from a 5-cent increase in the price of gasoline expressed as a percent of average driving costs

Burden per household (5 cent increase) as a percent of driving costs (rural)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Variable (used)	1.26%	1.00%	0.84%	1.10%
Variable (new)	1.30%	1.04%	0.86%	1.14%
Fixed (new)	0.43%	0.43%	0.41%	0.43%
Fixed (no depreciation or finance)	1.30%	1.30%	1.30%	1.30%
Total for new vehicles	0.32%	0.30%	0.28%	0.31%
Total for average Maine vehicles	0.64%	0.57%	0.51%	0.60%

Table E9. Economic burdens faced by urban households from a 9-cent increase in the price of gasoline expressed as a percent of average driving costs

Burden per household (9 cent increase) as a percent of driving costs (urban)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Variable (used)	2.18%	1.75%	1.46%	1.92%
Variable (new)	2.26%	1.81%	1.50%	1.99%
Fixed (new)	0.76%	0.76%	0.72%	0.76%
Fixed (no depreciation or finance)	2.28%	2.28%	2.28%	2.28%
Total for new vehicles	0.57%	0.53%	0.49%	0.55%
Total for average Maine vehicles	1.12%	0.99%	0.89%	1.04%

Table E10. Economic burdens faced by rural households from a 9-cent increase in the price of gasoline expressed as a percent of average driving costs

Burden per household (9 cent increase) as a percent of driving costs (rural)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Variable (used)	2.20%	1.76%	1.47%	1.94%
Variable (new)	2.28%	1.82%	1.52%	2.00%
Fixed (new)	0.76%	0.76%	0.72%	0.76%
Fixed (no depreciation or finance)	2.30%	2.30%	2.30%	2.30%
Total for new vehicles	0.57%	0.54%	0.49%	0.55%
Total for average Maine vehicles	1.12%	1.00%	0.90%	1.05%

Table E11. Economic burdens faced by urban households from a 17-cent increase in the price of gasoline expressed as a percent of average driving costs

Burden per household (17 cent increase) as a percent of driving costs (urban)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Variable (used)	3.95%	3.16%	2.63%	3.47%
Variable (new)	4.08%	3.26%	2.72%	3.59%
Fixed (new)	1.39%	1.39%	1.32%	1.39%
Fixed (no depreciation or finance)	4.20%	4.20%	4.20%	4.20%
Total for new vehicles	1.04%	0.98%	0.89%	1.00%
Total for average Maine vehicles	2.03%	1.80%	1.62%	1.90%

Table E12. Economic burdens faced by rural households from a 17-cent increase in the price of gasoline expressed as a percent of average driving costs

Burden per household (17 cent increase) as a percent of driving costs (rural)				
	10,000 miles per vehicle	12,500 per vehicle	15,000 per vehicle	11,363 per vehicle
Variable (used)	3.94%	3.16%	2.63%	3.47%
Variable (new)	4.08%	3.26%	2.72%	3.59%
Fixed (new)	1.39%	1.39%	1.32%	1.39%
Fixed (no depreciation or finance)	4.20%	4.20%	4.20%	4.20%
Total for new vehicles	1.04%	0.97%	0.89%	1.00%
Total for average Maine vehicles	2.03%	1.80%	1.62%	1.90%

AUTHOR'S BIOGRAPHY

William Lauring Somes was born in Virginia Beach, Virginia on July 16, 1998. His family moved to Columbia Falls, Maine when he was two years old, and he has lived in the state ever since. Somes attended Columbia Falls Elementary until the school was permanently closed in 2010. After finishing middle school at Daniel W. Merritt Elementary in Addison, Maine, he then attended high school at Washington Academy in East Machias, Maine. Here he played in various musical ensembles and was a member of the National and Tri-M honors societies. While in high school, Somes performed the third movement of the Bach double violin concerto as a soloist with the Bangor Symphony Orchestra.

After high school, Somes took a year off from school and studied violin with Robert Dan in Blue Hill, Maine. He then returned to school in the fall of 2017 to study political science and economics. While there, he participated in national and international conferences, worked as a research assistant for the Sustainable Ecological Aquaculture Network, published a novelette and several opinion editorials, and studied abroad at the American University in Bulgaria. Somes also performed with numerous ensembles such as the University Singers and the University Orchestra.

Somes plans to continue his research on environmental and climate policy as a graduate student. After completing a master's degree in environmental public policy, Somes plans to return to his home in Maine where he will run for state or municipal government.